THE TRUTH ABOUT AIR CARS
VOLUME 2

THE TROLLEY HAS A RIVAL.
From Chicago-Times Herald.

THE TRUTH ABOUT AIR CARS
VOLUME 2

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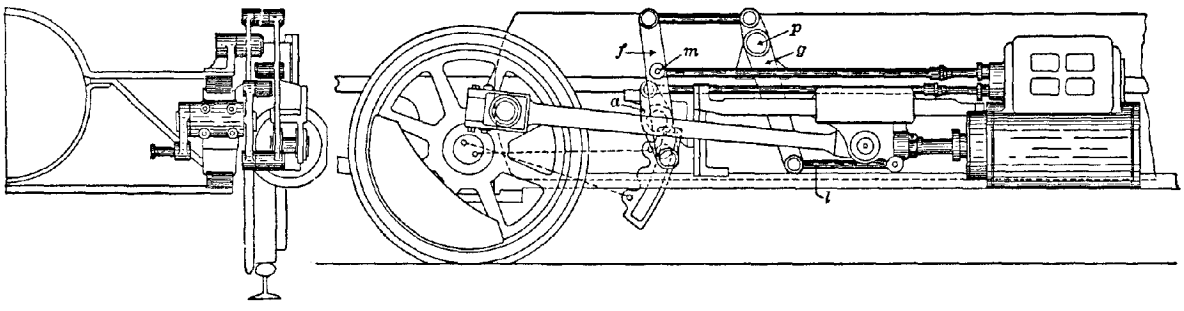


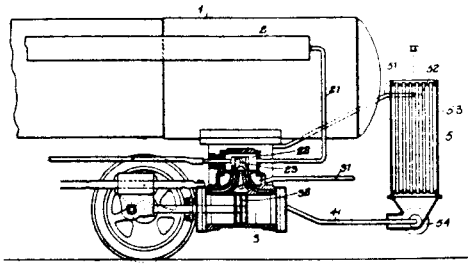
FIG. 412.—SIDE AND END ELEVATION OF THE MOTOR.

ABOVE: The Hardie Air Engine, used for street transit in New York City and Copenhagen

U. S. PATENT OFFICE.

OCTOBER 15, 1907.

868,560. INTERHEATER FOR COMPOUND COMPRESSED-AIR ENGINES. CHARLES B. HODGES, Pittsburg, Pa. Filed Oct. 10, 1904. Serial No. 227,862.



1. In a compound compressed-air engine in combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a receptacle for compressed air connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, and means for causing a current of air to flow over the surface of the said receptacle operative on the exhaust of air from the low-pressure cylinder, substantially as described.

2. In a compound compressed-air engine, in combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a receptacle for compressed air connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, and a passage for atmospheric air through said receptacle, the exhaust from the low-pressure cylinder being so arranged at the discharge end of said air passage as to draw atmospheric air therethrough, substantially as described.

3. In a compound compressed air engine in combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a receptacle for compressed air connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, passages for atmospheric air through said receptacles, the exhaust from said low-pressure cylinder being arranged to cause a flow of atmospheric air at normal temperature through the passages, substantially as described.

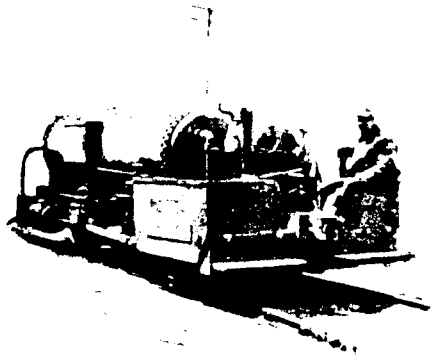
4. In a compound compressed-air engine, the combination with the high-pressure and low-pressure cylinders and their inlets and exhausts, of a casing arranged to permit the passage of a current of atmospheric air therethrough and provided with a flaring outlet, a receptacle for compressed air arranged within said casing and connected with the exhaust from the high-pressure cylinder and with the inlet to the low-pressure cylinder, the exhaust from the low-pressure cylinder being arranged to discharge into the flaring outlet of said casing, substantially as described.

5. An interheater for a compound compressed-air engine which consists of a receptacle receiving air from the high-pressure cylinder and delivering air to the low-pressure cylinder, said receptacle being provided with a surrounding fluid envelop, such fluid-enveloped surface being of relatively great extent and arranged and adapted to absorb heat from the atmosphere, substantially as described.

AN INDUSTRIAL COMPRESSED-AIR RAILWAY

COMPRESSED AIR LOCOMOTIVES IN THE ANACONDA COPPER MINING COMPANY'S NEW REDUCTION WORKS AT ANACONDA, MONTANA, U. S. A.

By C. B. Hodges

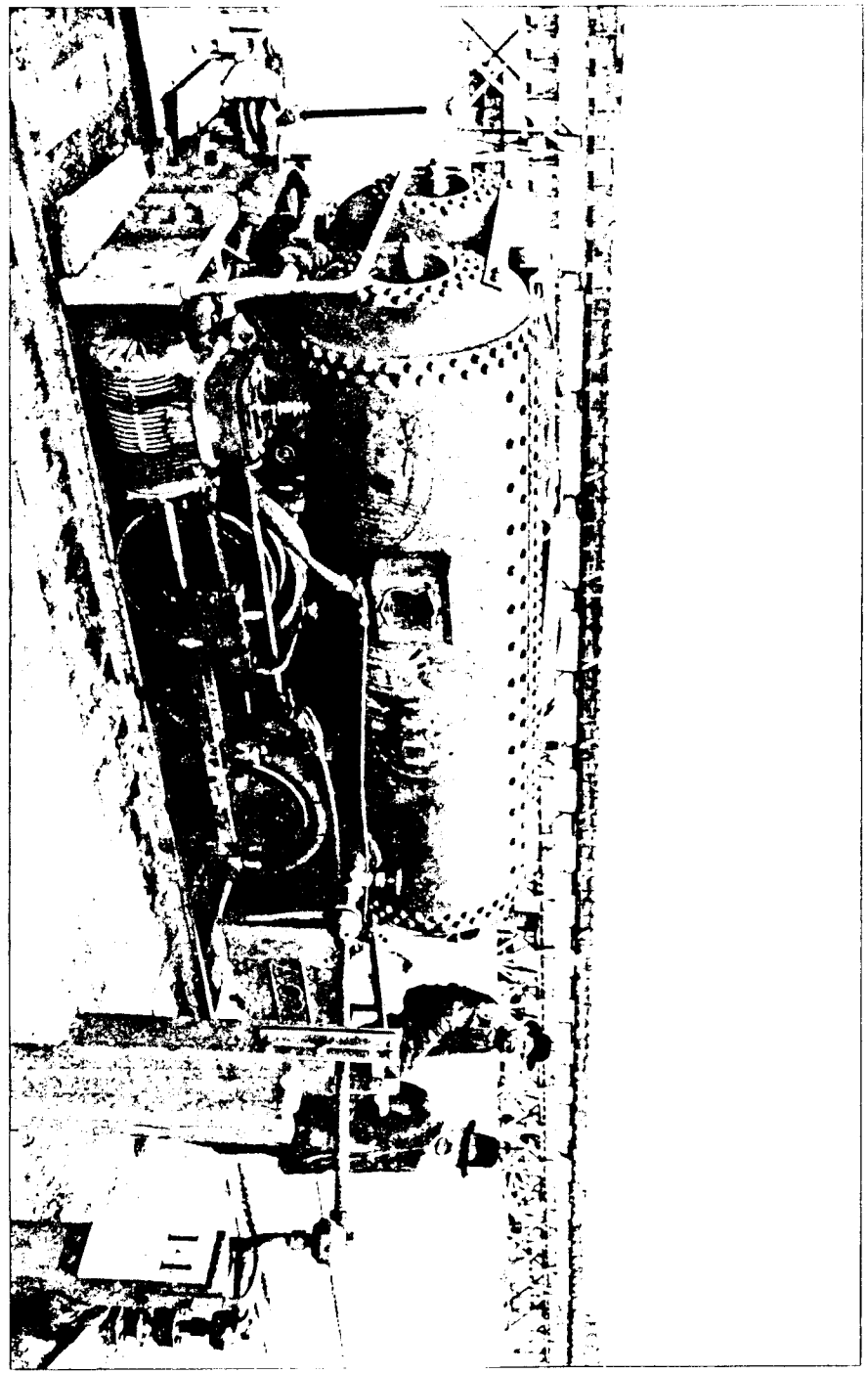


IN May, 1905, the writer became indebted to Mr. E. P. Matthewson, manager of the Anaconda Copper Mining Company's new reduction works, for opportunities offered to study their rather novel compressed air system of transportation. Compressed air locomotives are used at these works more extensively and continuously than at any other mine or works in the world. The Anaconda reduction works are operated twenty four hours per day, and seven days in the week.

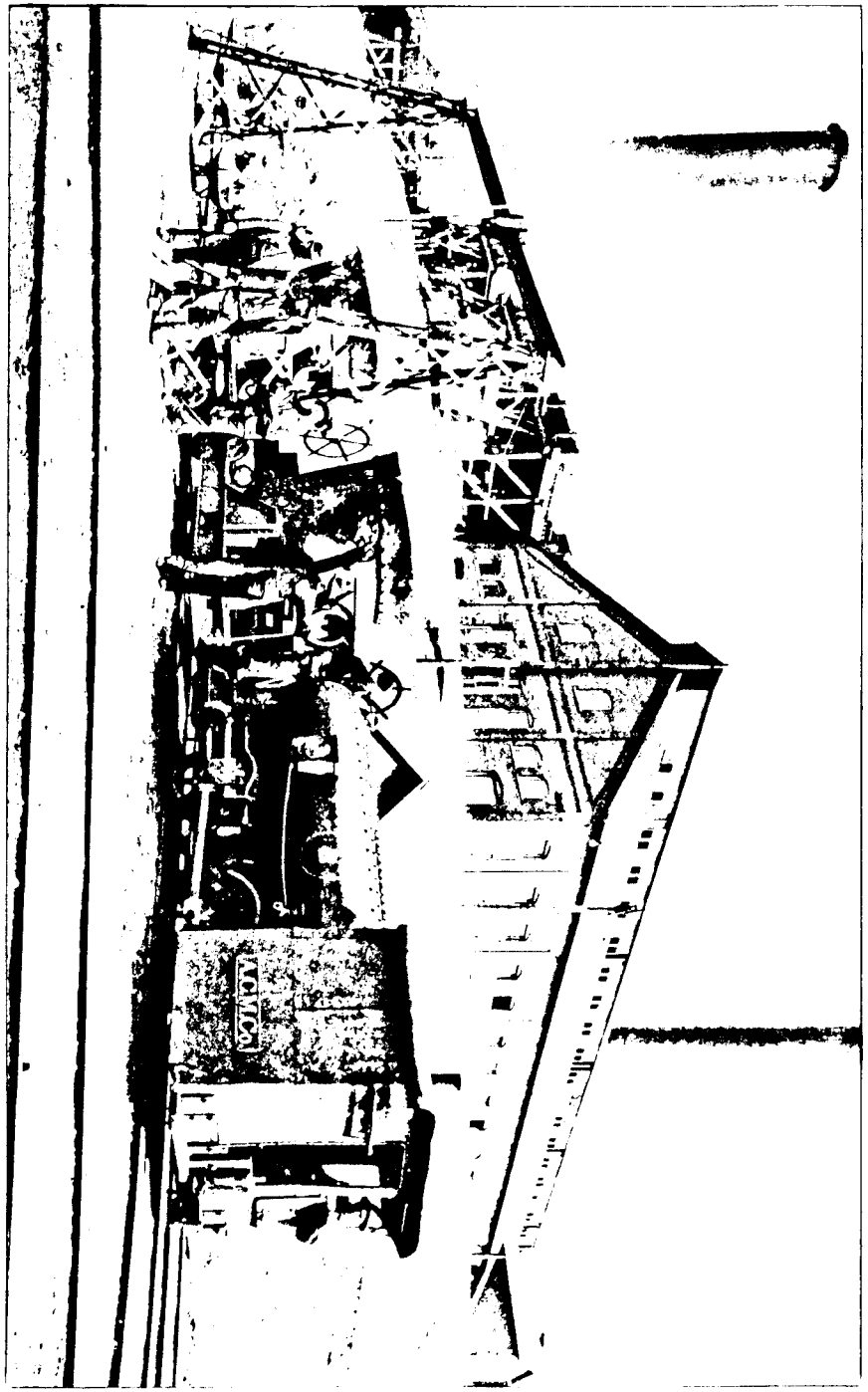
The company works eleven or twelve compressed air locomotives for sixteen hours each day, and nine for the remaining eight hours. It owns thirteen locomotives, as under the conditions practically continuous work is essential, and a spare locomotive is required in order that necessary repairs may be made. Twelve of these locomotives weigh 26,000 pounds each, have cylinders 9½ inches in diameter by 14-inch stroke; driving wheels 28 inches in diameter; a rigid wheelbase of 54 inches; main storage tanks of 132 cubic feet capacity; tractive force 5700 pounds. The remaining locomotive weighs 42,000 pounds, has cylinders 12 inches in diameter by 18 inches stroke; driving wheels 36 inches in diameter; a rigid wheelbase of 60 inches; main storage tanks of 218 cubic feet capacity; tractive force 9180 pounds.

The main storage tanks are charged, at intervals of from twenty minutes to one hour, with air at a pressure of from 700 to 800 pounds per square inch, which is then reduced to a pressure of about 150 pounds for use in the cylinders of the locomotives. When the pressure in the main storage tanks, as shown by a gauge facing the engineer, has dropped to a point near 150 pounds per square inch, the locomotive is stopped at the next charging station and recharged, this operation of recharging taking from one to two minutes.

The machinery on these locomotives is in most respects the same as would be employed on a steam locomotive of the same size, the chief difference being that the cylinders are ribbed, in order that they may the more rapidly absorb heat from the atmosphere, instead of being lagged to prevent the loss of heat, as is the case with steam locomotives. The compressed air goes into the main storage tanks on the lo-



A LOCOMOTIVE BEING CHARGED WITH AIR. THE ENTIRE OPERATION OF COUPLING, CHARGING, AND UNCOUPLING IS FREQUENTLY PERFORMED IN LESS THAN A MINUTE AND A HALF. ALL THE COMPRESSED AIR LOCOMOTIVES CONSIDERED IN THIS ARTICLE WERE BUILT BY THE H. K. PORTER CO., PITTSBURGH, PA.



A HOT METAL TRAIN OF LADLE CARS AT SCALES WHERE THE METAL IS WEIGHED

comotives at atmospheric temperature, and falls to a temperature far below that of the atmosphere during the expansion in the cylinders. This feature has an important bearing upon the relative efficiencies of the three great powers,—steam, electricity and compressed air, under certain conditions.

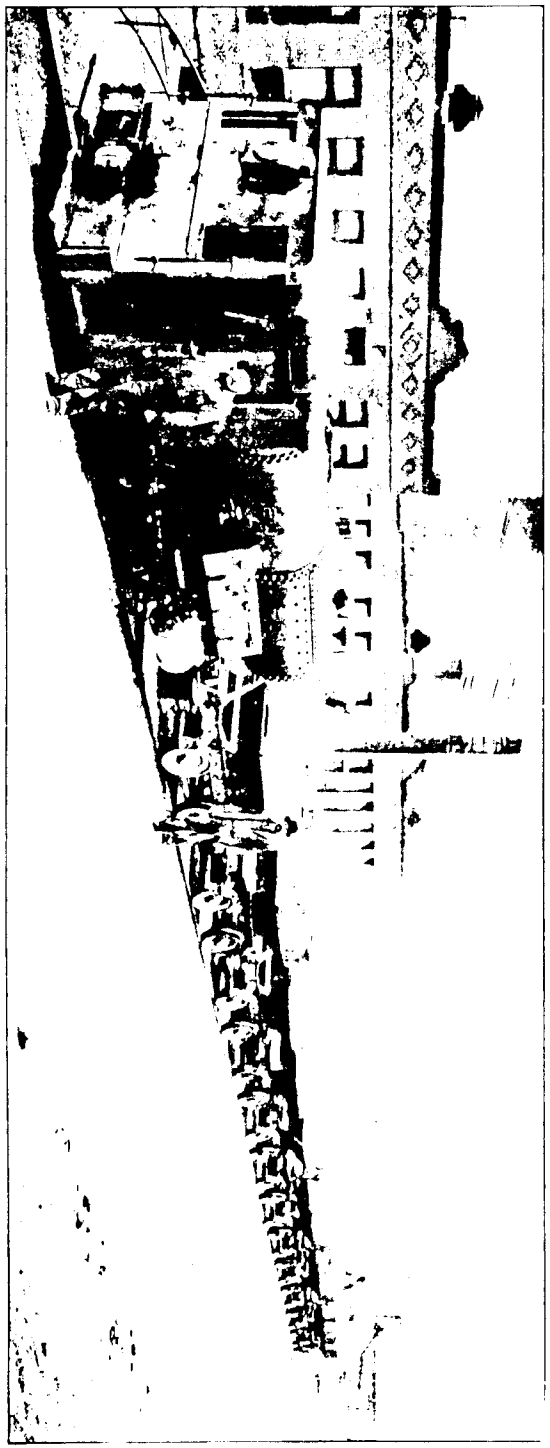
An electric motor is an inefficient machine while coming up to normal speed; a steam engine is inefficient until the walls of the cylinders are thoroughly heated; but a compressed air engine is most efficient, thermodynamically, with the first movement of the piston, because the walls of the cylinders are then at their highest temperature. This fact would point to the use of compressed air locomotives wherever stops and starts are to occur with great frequency. The main storage tanks on the air locomotives replace the boiler, and need but little description. They are exceptionally good pieces of work, having required no repairs during four years of service; they are to-day practically bottle-tight. The locomotives stand for hours without perceptible loss of pressure.

The regulating valves on the locomotives deserve special attention. To make the locomotives successful, this piece of apparatus must at all times maintain, with the minimum amount of attention, a practically uniform pressure in the small auxiliary reservoir located between the regulating valve and the throttle valve, and be absolutely tight when the locomotive is at rest. How well the regulating valves on these locomotives perform is evident to anyone who rides on them. The gauge-hand that indicates the pressure in the auxiliary reservoir is apparently glued to the 150-pound mark on the gauge while the locomotive is in motion, and it seldom rises above 175 pounds while the locomotive is at rest.

The compressed air required by the locomotives is furnished by two compressors, having cross-compound steam cylinders equipped with Corliss valve-gear, and four-stage air cylinders. The compressors are duplicates. The high-pressure steam cylinder is 20 inches, and the low-pressure steam cylinder, 40 inches in diameter; all air cylinders are single-acting; the intake air cylinder is 37½ inches in diameter, first intermediate cylinder 20½ inches, second intermediate cylinder 12½ inches, high-pressure cylinder 6 inches, and the common stroke is 48 inches. The intake and first intermediate cylinders are placed behind one steam cylinder; the second intermediate and high-pressure cylinders behind the other. All the air cylinders are water-jacketed, and intercoolers are provided for cooling the air after each stage of compression.

The compressors are equipped with automatic speed and pressure governors, and an examination of the sheets taken from the recording gauge shows that the regulation of pressure is absolutely perfect. They are operated with steam at 150 pounds pressure and with a vacuum of 17 inches in the condenser, perfect vacuum at the elevation being 24 inches. The rated speed is 70 revolutions per minute; the horse-power developed per revolution, 8.7; the steam consumption per horse-power-hour when operating at a speed of 55 revolutions per minute, 18.67 pounds. The company intends to improve the vacuum in the near future, which will undoubtedly result in a lower steam consumption.

The remainder of the haulage equipment consists of a system of piping varying in size from 2 to 6 inches. This serves two purposes:—First, it connects the compressors with the various charging stations; second, it provides a reservoir containing a reserve supply of compressed air at a pressure in excess of that required by the locomotives, and sufficient to charge one or two locomotives instantaneously. Although this pipe line sustains a pressure of 950 pounds per square inch and con-



TRAIN CARRYING COARSE CONCENTRATES. THE LOCOMOTIVE WEIGHS 42,000 POUNDS, AND TRAVELS 14,000 FEET IN MAKING ONE ROUND TRIP. BOTH LOCOMOTIVE AND TRAIN ARE EQUIPPED WITH WESTINGHOUSE AIR BRAKES

sists of several thousand feet of pipe of various sizes, with many branches, valves, and charging station connections, leaks are extremely rare and it requires a rather tedious search to discover one. The losses due to this cause must be small indeed, as a leak of any importance is readily heard by any person within a radius of 10 feet.

The compressed air locomotives are operated over about 18 miles of standard gauge track laid with 60-pound rails, located inside of an irregular area about half a mile square. The reduction works are located on a side hill, and the locomotives, in doing their varied work, pass from the bottom of one building to the top of another, under the dripping bins from which the concentrates are drawn, and over, under and around the furnaces, in an atmosphere of heat, dust and sulphurous acid, with sharp curves, steep grades, and loads that tax their capacity to the extreme limit.

Outside the buildings the locomotives are subjected to extremes of weather. At an elevation of 5000 feet above sea level, at Anaconda, Mont., the range of temperature is from 95 degrees above zero to 35 degrees below, with heavy snows and high winds. Under these conditions the records of the company show that the compressed air locomotives, during the months of January, February and March, 1905, lost 5¾ hours for one locomotive out of a total of 22,320 locomotive-hours, distributed among thirteen locomotives. These records show all delays chargeable to failures of the transportation system and are kept with great exactness.

The new reduction works were first operated in February, 1902. The locomotives in question have been the only means of internal transportation since the first pound of copper was produced, and the nine original locomotives, purchased in November, 1900, which were used during construction, are still in service and apparently as good as new, except for the necessity for regular running repairs. The tabulated data on this page give a rough idea of the work which is being performed.

It should be understood in reviewing the table that it does not by any means represent all the work done by the locomotives. The first omission is the movement of the locomotives themselves, both when hauling trains and when running light from point to point; second, the endless "spotting" and shifting that is necessary in order to weigh, load, and unload the material hauled. For example, in the case of the locomotive hauling hot metal, the cars or ladles must be spotted for weighing three times on each round trip, in addition to three other stops,—two for loading and un-

PERFORMANCE OF COMPRESSED AIR LOCOMOTIVES

Number of Locomotives	MATERIAL	Quantity in Net Tons	Weight in Lbs. of Empty Car	Average Weight in Lbs. of Load on Each Car	Number of Cars Per Train	Number of Trains Per Shift	Number of Shifts Worked	Distance in Feet
1	Coarse concentrates, first-class ore, converter lining and lime rock	1200	7,500	16,666	12	6	2	7,000
1	Fine concentrates	1746.54	6,400	18,192	6	10 or 11	3	2,000
1	Coal	360	6,200	6,545	6 or 7	5 or 6	3	3,400
2	Calcines	1450	6,500	10,175	3	32	3	1,500
1	Hot metal	731.42	23,200	19,505	1 or 2 seldom 3	13 to 15	3	1,800
3	Coarse concentrates, flue dust, first class ore, clay and lime rock	3600	4,200	4,286	2 trains 16 cars 1 train 20 cars	33	3	1,600
1	Miscellaneous	1400	32,000	53,000	1 or 2	13	3	1,000
1	Miscellaneous	950	6,400	9,000	1 to 20	12	2	1,000
	Total	11,437.96						

MATERIAL	Grade	From	To	See Note	Ton Miles Exclusive of Locomotives Net	Ton Miles Exclusive of Locomotives Gross
Coarse concentrates, first-class ore, converter lining and lime rock	2% A. L.*	Upper part concentrator	Stock bins	A	2,120	4,027
Fine concentrates	1% A. L.†	Lower part concentrator	Roaster building		662	1,127
Coal	Level	Stock bins	Reverberatory furnaces		232	671
Calcines	Level	Roaster	Reverberatory furnaces		412	938
Hot metal	Level	Reverberatory and blast furnaces	Converter	B	207	684
Coarse concentrates, flue dust, first class ore, clay and lime rock	Level and 2% A. L.†	Stock bins and brick plant	Blast furnaces	C	1,090	3,225
Miscellaneous		Between all points		D	267	581
Miscellaneous		Between all points		D	140	340
Total					5,170	11,593

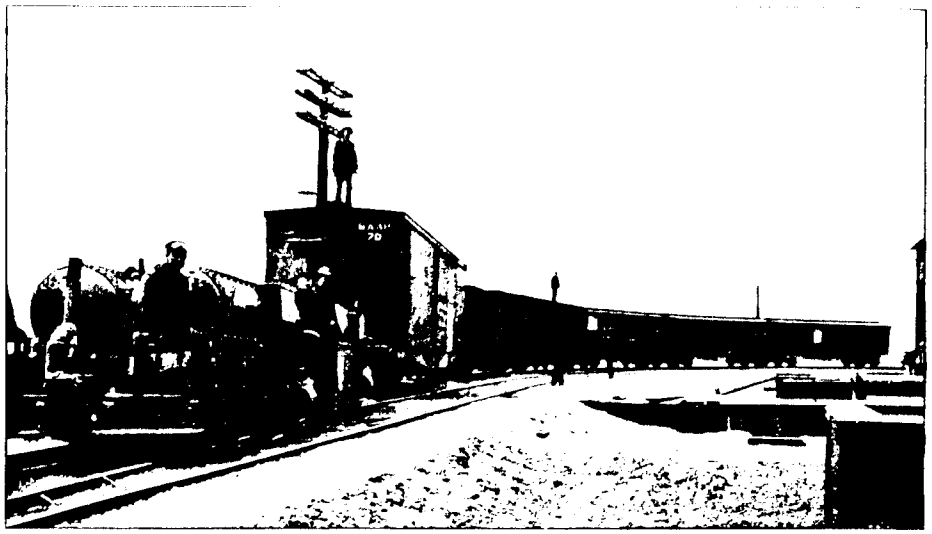
NOTE A.—A 42,000 pound locomotive. This locomotive also shifts 5 or 6 standard railroad cars per day, and also 1 large wood car per day, equivalent to about 2 more round trips per shift.

NOTE B.—Each round trip includes trip through Y for cleaning ladle and three weighings.

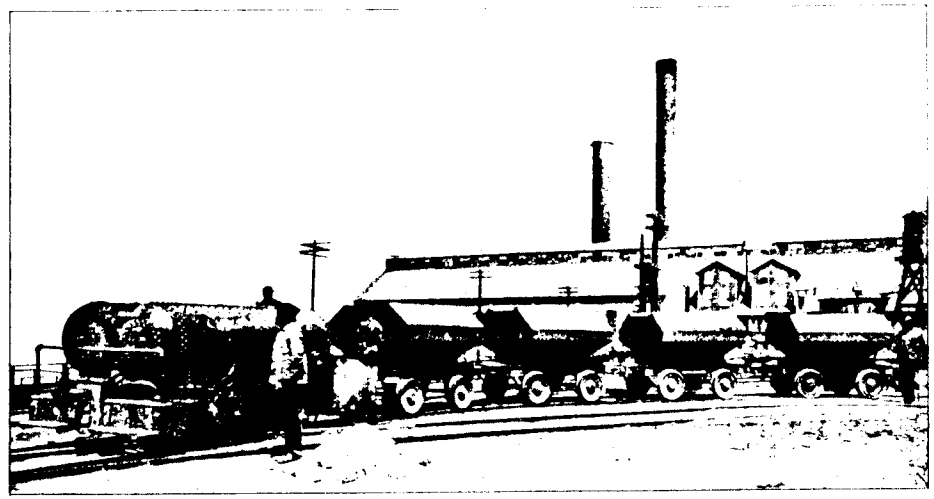
NOTE C.—Each round trip includes side trips to various locations under stock bins and to brick plant, then to blast furnaces.

NOTE D.—Miscellaneous shifting of standard railroad cars and plant cars, handled by both locomotives. This work is roughly estimated.

*In favour of loads. †Against loads.



TWO 26,000 POUND LOCOMOTIVES HAULING A TRAIN OF BOX CARS, LOADED WITH COKE, TO THE BLAST FURNACE



THE TRAIN CARRYING CALCINES RUNS BETWEEN THE ROASTER PLANT AND THE REVERBERATORY FURNACES COLOURED MEN OPERATE THIS LOCOMOTIVE BECAUSE THEIR SKIN STANDS THE GASES AND HEAT BETTER THAN THE WHITE MAN'S

loading, and the third for cleaning the ladle, this latter operation being performed on a spur leading off a Y.

In the case of the three locomotives hauling coarse concentrates, first-class ore, flue dust, slag, and limestone from the stock bins and brick plant to the blast furnaces, each carload must contain its proper proportion of each of the various ingredients, and each car must be "spotted" under the proper chute and weighed after each class of material is put in. At the other end, the train of from sixteen to twenty cars is moved back and forth eight or ten times in placing the various cars so that they can be unloaded in the proper place, in the proper furnace. Even the easiest runs involve at least two weighings of the train—one loaded and the other empty—and several shifts to place the cars at the proper points for loading and unloading. All this is necessary in order that the efficiency of the various operations may be traced at all times.

Samples of crude ore, concentrates, calcines, slags, flue dust and the metallic product of the blast and reverberatory furnaces, together with the black copper from the converter, are taken daily and analyzed. This combination of systematic weighing of all materials after every process, with daily sampling and analyses, enables the management to detect and stop promptly any unusual losses in the process.

To do this work, locomotives were required that were self-contained, reliable, powerful, smokeless, compact, and simple in operation. With steam locomotives the smoke and steam in the tunnels under the bins and furnaces would have made it almost impossible for the locomotive runner to see the signals. Electric locomotives would have required trolley wires or a third rail, either of which would have introduced serious difficulties in many locations too obvious to require explanation. Storage battery electric locomotives might have been used, but they are not adapted to severe and continuous service, and require too long a time for recharging the batteries or changing the cells.

When the reduction works were built, the engineers in charge decided in favour of compressed air locomotives as the best solution of the transportation problem. Their successors who now operate the plant apparently agree with them, as they have purchased additional compressed air locomotives, and have extended the system to cover movements of materials which the constructing engineers did not consider in connection with the original design. The writer heard but little criticism and much commendation. The general opinion of the operating force is thus summarized:—Under their conditions, compressed air locomotives are unsurpassed for convenience, reliability, and simplicity of operation.

Taking up the question of economy, the labour cost of operating the system is as low or lower than it would be with any other system. With them the cost of power is also extremely low, as the steam is generated by waste heat from the reverberatory furnaces; but as the question of steam economy is of considerable interest under other conditions, and as an absolute determination was impossible under the circumstances, the writer will attempt a few comparisons, trusting that they may be found of interest.

During the month of April, the two compressors were operated continuously twenty-four hours a day, one at an average speed of 38.8 revolutions per minute; the other at 44.1 revolutions per minute. Under these conditions the total power developed would be 721 H. P. for both compressors, or an average of about 66 H. P. for each locomotive in operation. Ten out of the eleven locomotives in operation will develop 5700 pounds tractive force; the remaining locomotive will develop 9180 pounds. The speed is limited to 5 miles per hour.

Each one of the smaller locomotives would therefore be developing

$$\frac{5700 \times 5280 \times 5}{60 \times 33000} = 76$$

horse-power at times; the large one

$$\frac{9180 \times 5280 \times 5}{60 \times 33000} = 122$$

horse-power, giving a total of $76 \times 10 = 760$, added to $122 = 882$ horse-power.

The approximate kilowatt input of an electric locomotive of the same weight as the smaller type of compressed air locomotive would be 95, and for the larger size 150; total, 95 ×

10 = 950; 150 × 1 = 150; 950 + 150 = 1100 kilowatts.

If we assume that not more than one-half of the total rated capacity of the locomotives will be called for at any one time, we have 550 kilowatts, or 550 × 1.34 = 737 electrical horse-power at the locomotives, to which must be added 5 per cent. for line losses, 5 per cent. for dynamo losses, and about 7 per cent. for the friction of the engine: 737 × 1.17 = 862 for the indicated horse-power of the engine driving the dynamo to operate the same number and weight of electric locomotives, with occasional overloads and the extreme fluctuations incident to the operation of electric locomotives. It does not seem, therefore, as though electric locomotives under the same conditions would be much more economical of steam.

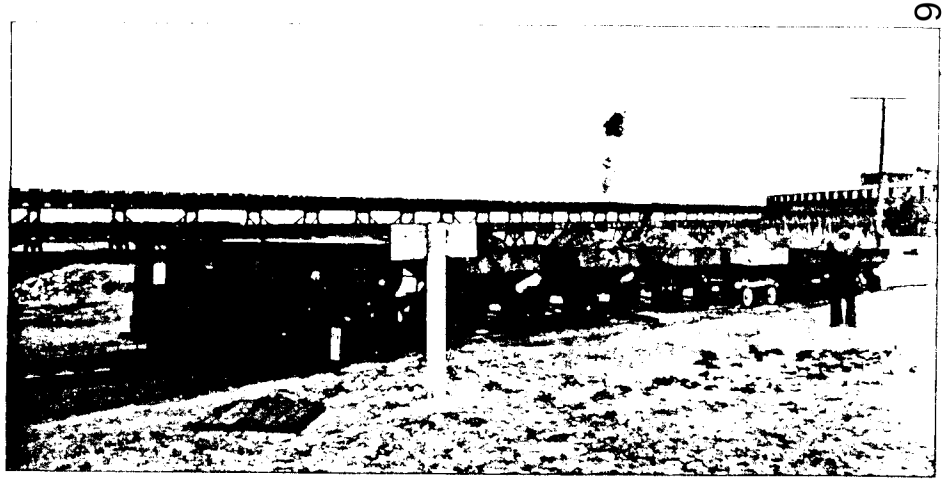
As compared with steam locomotives, in order to make an intelligent comparison we must go back to the coal pile, even though the steam necessary to operate the compressed air locomotives at the reduction works is obtained from boilers that are run by waste heat

The two compressors, under normal conditions, required 323,100 pounds of steam per day of twenty-four hours. By referring to the table on page 471 we see that there are thirty-one eight-hour locomotive shifts in each day of twenty-four hours. Assuming, for the sake of comparison, an evaporation of 7½ pounds of water per pound of coal, we find that to furnish steam for the compressors, 43,080 pounds of fair coal would be required, or, say, 1400 pounds of coal per compressed air locomotive shift. The writer has in his possession reports on the performance of twelve steam locomotives, having cylinders 9 inches in diameter by 14 inches stroke, which used from 760 to 2400 pounds of coal per day of ten hours, averaging about 1340 pounds.

Assuming that steam locomotives at the reduction works would use approximately the same quantity of fuel per hour, we have 1072 pounds for the small locomotives per shift, and 1500 pounds for the large one, giving a total of 1072 × 20 = 31,088, 1500 × 2 = 3000, 31,088 + 3000 = 34,088, or, say, 17 tons of coal for the steam locomotives doing the same work, as against 21½ tons for the compressed air locomotives.

These calculations are, of course, nothing more than crude approxima-

A "TRAMP" LOCOMOTIVE AND CARS FOR MISCELLANEOUS WORK



FINE CONCENTRATES TRAIN. THE LOCOMOTIVE HAS A ROOF OF SHEET METAL TO PROTECT IT AS MUCH AS POSSIBLE AGAINST THE DRIPPING BINS FROM WHICH THE CONCENTRATES ARE DRAWN

tions, and are presented only as indicating that any change which might be effected in the cost of steam to operate the transportation system by substituting another form of motive power would be of minor importance when considered in connection with other expenses and the other desirable qualities of the existing system.

The cost of maintenance must certainly be less than with steam locomotives by about the amount necessary to wash out and keep in repair thirteen small locomotive boilers, as the cost of keeping the main storage tanks on the compressed air locomotives in repair has been nothing. The remainder of the machinery of the compressed air locomotives being so nearly the same as that of the steam locomotive, there is no reason why there should be any difference in the cost of maintenance. The writer is of the opinion that the repairing of saddle tanks and the renewing of grate bars on steam locomotives would about balance any expenditure for maintenance of a stationary plant, including the boilers.

In comparing the cost of maintenance with electric locomotives no such direct deductions are possible. The machinery is radically different, and the friends of both systems claim superiority in this respect for their favourites. With the electric locomotives, dust and dirt are more easily kept away from the wearing parts; but the same casing that keeps out the dust prevents the free circulation of air around the armature and commutator, and renders them more liable to injury from overheating. So little reliable data is to be had that it is all a matter of opinion. Figures have been published showing that compressed air locomotives are more economical to maintain than are electric locomotives, but there are no detailed and reliable figures to show electric locomotives more economical than compressed air locomotives.

One set of figures, however, does not settle the matter. Probably local conditions and designs have more to do with the relative cost of maintenance than any inherent qualities of the two systems. Compressed air locomotives have this advantage: charge after charge of air may be used in quick succession, with the locomotive working at all times at full capacity without injury. This is not true of electric locomotives. The electric motors which drive the locomotives are so designed that they can be run for one hour at rated draw-bar pull

and speed without injurious heating, provided the motors are started cold. As a rule, this provision is sufficient, but occasionally it is not, and a burnout occurs.

The problem of internal transportation in many large establishments is a serious one, and during the writer's stay at Anaconda the many advantages of compressed air locomotives for such service were so manifest, and the evidence that their development had reached a stage justifying the confidence of engineers and business men was so conclusive, that a brief account of what was being accomplished with this form of motive power seemed of general interest.

Compressed air locomotives, however, have their limitations. They are not intended for long continuous runs in one direction, and their efficiency would be relatively low where starts and stops were infrequent; but for service conditions similar to those existing at the Anaconda Copper Mining Company's new reduction works there would seem to be a wide field of usefulness, more especially where waste heat from heating or blast furnaces, or the refuse from woodworking establishments, or water power, could be utilized to operate the compressor, thus saving the fuel necessary to operate steam locomotives, doing away with trolley wires, and eliminating all risk of fire.

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HOISTING
HAULAGE
MINE DRAINAGE

1907

SCRANTON

INTERNATIONAL TEXTBOOK COMPANY

COMPRESSED-AIR LOCOMOTIVES

42. General Design.—To meet the varying conditions of height and width of the mine passages, there is considerable diversity in the design and size of **compressed-air locomotives.** Some have six driving wheels and some four; some have the cylinders outside the frame and others have them inside the frame. For easy grades, short hauls and light loads, the single air-tank locomotive of modern dimensions and designed for a pressure of 600 pounds per square inch may be sufficient, and in some cases even lower pressures may be used, but there is more economy in the use of reasonably high pressures. For longer hauls and greater tonnage, larger air capacity is usually needed and two or more storage tanks, designed for a pressure of 800 or 900 pounds per square inch, are required. Very limited height and width of mine entries may compel the use of tanks of small capacity and the use of high-pressure air.

43. Fig. 4 shows a compressed-air locomotive intended for service where the haul is not long and is therefore fitted with a single storage tank. These locomotives weigh from $2\frac{1}{2}$ to 10 tons, the lighter weight locomotive having $4'' \times 8''$ cylinders and the heavier weight having $8'' \times 14''$ cylinders. The smaller sizes are adapted to the narrow gauges and sharp curves common in gold, silver, lead, and copper mines, while the larger sizes are mainly used in main and cross-entry haulage of coal mines.

In the illustration, *a* is the main storage tank and *b* the auxiliary tank. Air is admitted to the air chests *c* through a branch pipe *d*, leading from the pipe *e*, connected with the auxiliary tank *b* by means of the throttle valve *f* worked by the reach rod *g* and lever *h* in the cab. The piston rod *i* reciprocates in cylinder *j*, and is attached to a crosshead *k* that slides on the guide bar as shown. The back driving wheels *l* are connected by the main rods *m*, with the crossheads *k* and by the side rods *n* with the front drivers *o*. The valve rods *p* are connected by the rocker *q* with the eccentric shaft. The lever *r* shown in the cab is for reversing the engine and for shortening the throw of the valves, thus making the machine use air expansively and economically. The locomotive is provided with brakes, oil cups, pressure gauges, and tools necessary for keeping the machine in working order.

44. Compound compressed-air locomotives, although very efficient when tested in the shop, are not so well adapted to mine service as the single-expansion type, owing to the fact that there are twice as many cylinders, pistons, stuffingboxes, etc., on a compound as on a single-expansion locomotive, thus giving twice the chance for leakage. Furthermore, it is well known that mine machinery is used under adverse conditions and does not generally receive the same care [illegible] in daylight, hence the simpler the [illegible]

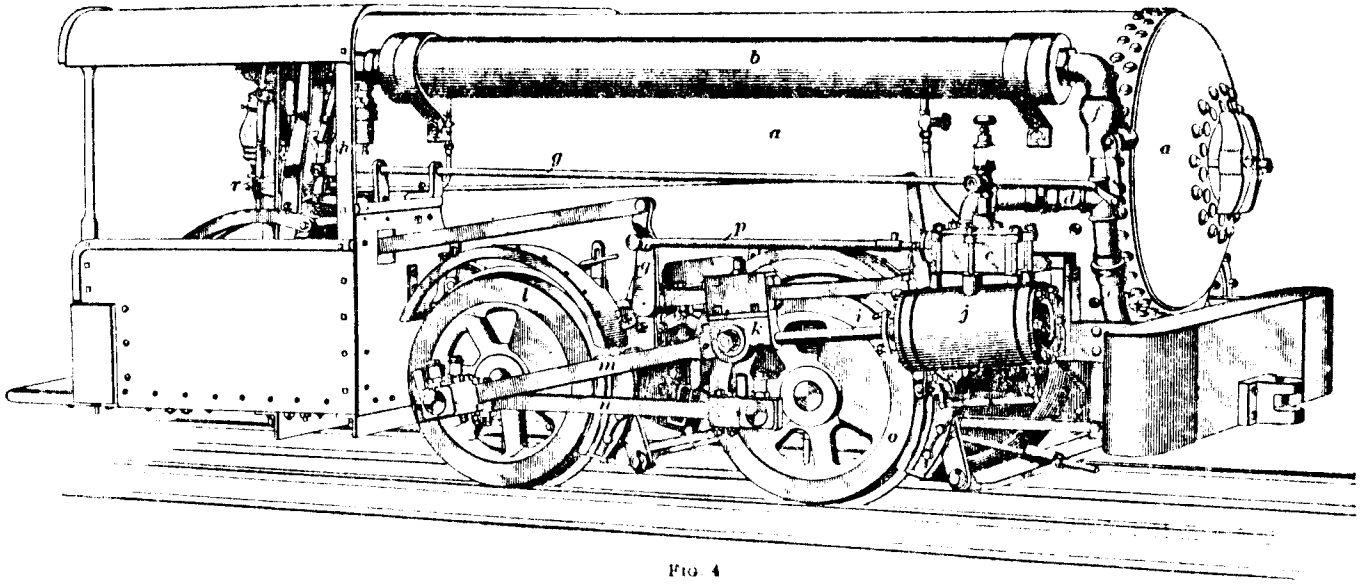


FIG. 4

45. The compressed-air locomotive shown in Fig. 5 has two storage tanks *a* with a total storage capacity of 133 cubic feet and the following general dimensions: diameter of drivers, 24 inches; cylinders, 7 in. × 12 in.; wheel base, 4 feet 6 inches; gauge, 3 feet; weight, 19,700 pounds.

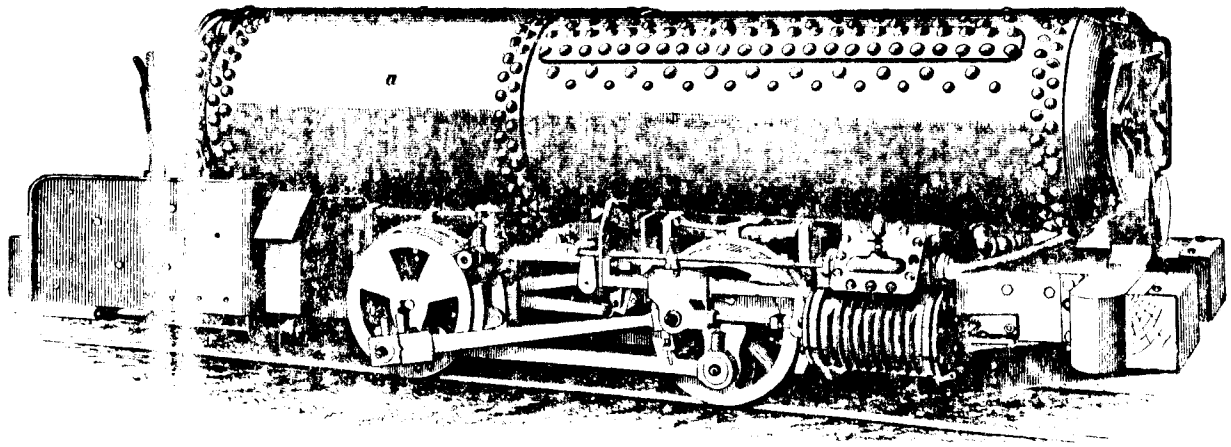


FIG. 5

46. Locomotives With Air-Tank Tenders.—Where unusually long hauls or heavy grades make it advisable to provide a greater reserve of energy than can be stored in the one or two tanks of an engine, additional storage tanks can be mounted on a truck and serve as a tender for the locomotive. The tender can be uncoupled and the locomotive operated separately when it is needed on short hauls; but where the haul is long and the air storage pipes are not continued to the end of the run, the locomotive may, by carrying a tender, make the round trip with one charge.

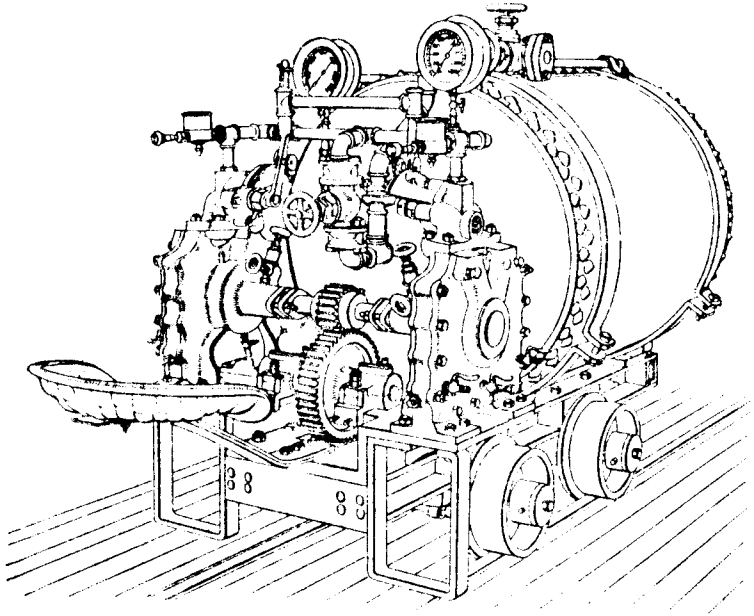


FIG. 6

47. Special Geared Locomotive.—Fig. 6 shows an unusual form of locomotive used at Grass Valley, California, for hauling a trip of five cars, each carrying 1 ton, over a round trip of 5,000 feet. The air tank is 36 inches in diameter and 48 inches long, and carries an air pressure of 500 pounds per square inch. The locomotive is 5 feet long over all, 30 inches wide, 4 feet 4 inches high, and runs on a track only 18 inches wide. It is operated by a pair of geared engines enclosed as shown, which is of particular advantage in wet and muddy mines.

48. Compressed-Air Gathering Locomotives.—Owing to the sharp curves made from entries into the rooms in coal mines, special small compressed-air locomotives are used in some cases to deliver empty cars to the miners and remove loaded cars to the partings. Fig. 7 shows a gathering locomotive built for the Consolidation Coal Company of Georges Creek coal field in Maryland. The machinery on this locomotive is placed inside the frame

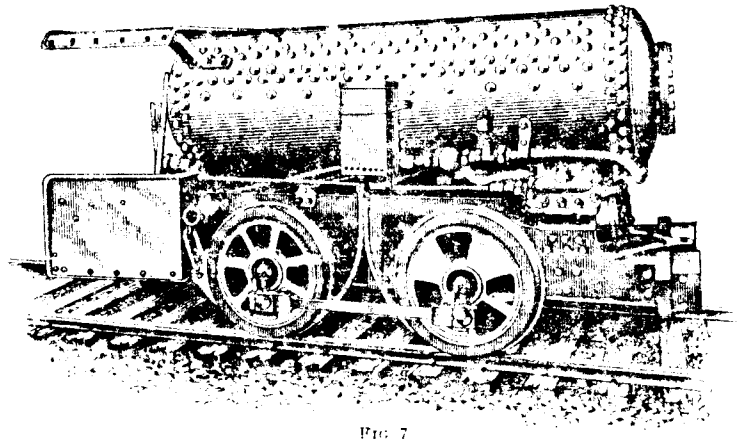


FIG. 7

so that it will not extend beyond the ties and graze the ribs. This is made necessary because the rooms are only from 12 to 15 feet wide and are timbered with a collar and post, the latter standing in the center of the room, or just far enough to one side to permit a car to pass. The tracks in the rooms for these locomotives are not much better laid than for the cars where mules do the hauling. A loaded car weighs 7,000 pounds and a locomotive 8,000 pounds, so that track that would be safe for the car would probably be safe for the locomotive.

In the actual placing of cars in the workings, a gathering locomotive has no advantage over a mule, but a broken locomotive can usually be repaired over night, while an injured mule can only be replaced by a new one, so by the use of locomotives the work is less likely to be interrupted. The speed with which the cars can be hauled along the entries to the parting is in favor of the locomotive.

49. Fig. 8 shows a gathering locomotive used in the anthracite mines of the Delaware & Hudson Company near Scranton, Pennsylvania. This locomotive is intended to gather the cars from rooms worked in very thin coal and into which it is impossible to take a mule without blowing down the top or lifting the bottom. It is therefore made

very low. Its general dimensions are as follows: diameter of cylinder, 7 inches; stroke of piston, 14 inches; diameter of driving wheels, 24 inches; wheel base, 3 feet 4 inches; total length, 12 feet 3 inches; height, 2 feet 11 inches; width, 5 feet 4 inches; storage capacity for air, 40 cubic feet; storage pressure, 700 pounds per square inch; working pressure, 125 pounds per square inch; weight, 12,000 pounds.

The main storage tanks consist of nine steel tubes *a* laid and bound together as shown in Fig. 8 and in section in Fig. 9. These tubes are connected by copper pipes and extra heavy brass fittings to a pipe that has two connections with a pressure auxiliary tank *b*, Fig. 9. The storage tanks

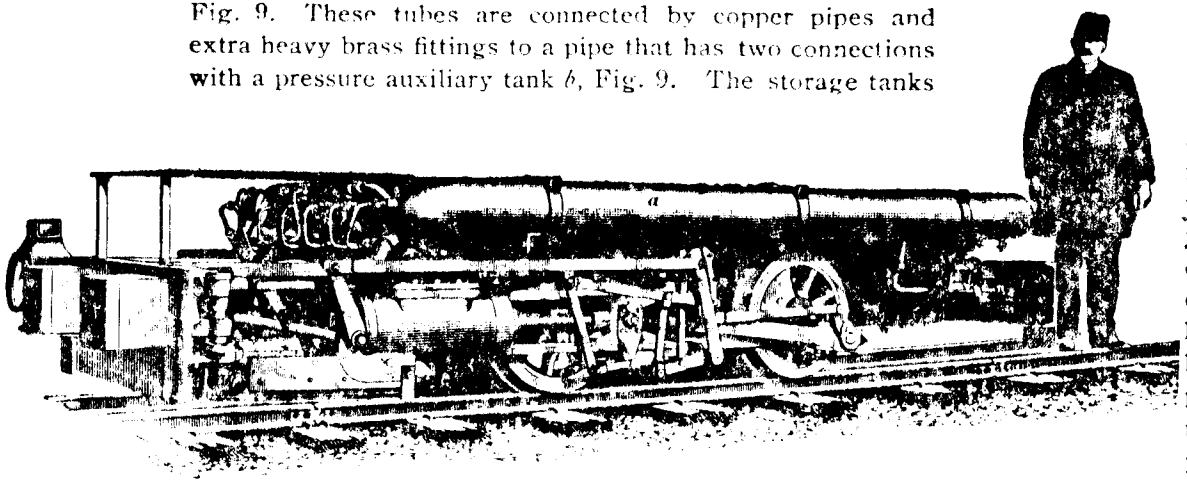


FIG. 8

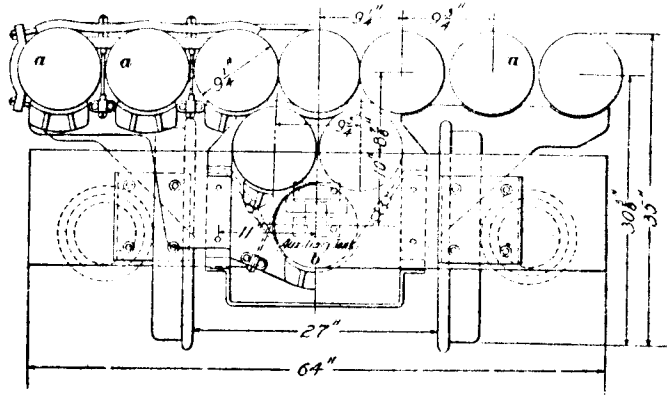


FIG. 9

are arranged in two series, each with a suitable shut-off valve and each having independent filling connections and check-valves. By this arrangement, if the connection of either series fails, it can be cut off and the other used. The location of the storage tubes between the side frames prohibits the use of a link valve motion and eccentrics, and instead the valve gear is placed outside the frame. This gear, Fig. 8, is operated by a lever through the crank *b* and rod *c*. The operator's cab is necessarily small and is placed at the cylinder end of the locomotive and between the side frames. In case of derailment, it is protected by the bumpers.

50. Locomotive Storage Tanks.—The air-storage tanks are made of thick, flanged steel plates. The longitudinal seams are sextuple- or octuple-riveted with butt joints and welt strips inside and out; the girth seams are double-riveted. The welt strips add stiffness to the tank plates, at the same time, as arranged, they strengthen the longitudinal joints. They are more useful in long tanks than in short ones, also in tanks of large diameter than in those of small diameter, as they counteract the tendency to bulge. The heads of the tanks are made convex and in one piece; the front head, however, is sometimes cut for a manhole and the tank plate about the hole is reenforced by a steel casting. The manhole cover is of cast steel and is held in place by steel yokes, bolts, and nuts, and by this means the tank may be entered either for inspection or for repairs. Each tank is made absolutely tight and is tested by hydraulic means, to a considerably higher pressure than it is to carry.

The thickness of the tank plates is proportioned to the pressure to be carried and to the design of the tanks, and is such as to secure a large factor of safety. When pressures above 1,000 pounds per square inch are required, tanks of large diameter cannot be safely employed and a series of heavy seamless steel tubes are used as storage tanks. Tubes of this kind, 9 inches in diameter and $\frac{11}{32}$ inch thick, when made of high carbon steel will safely carry a pressure of from 2,000 to 2,500 pounds per square inch; such high pressures are not employed for mine haulage. It is possible to charge the storage tanks to a higher pressure than is absolutely necessary, thus accumulating a reserve power. This may be advisable, since on up grades locomotives use more power than on the level.

51. Size of Locomotive Storage Tanks.—In order that compressed-air locomotives may be able to make their trips from a charging station to the end of the haulage system and back, or from one charging station to another, their storage tanks must be of such proportion as to hold the proper quantity of compressed air.

In order that locomotive storage tanks may be designed correctly with a minimum storage space for the maximum work to be done, it is necessary to have a complete profile of the road over which the locomotives are to travel, and from this a tabulated statement of the air consumption on the various grades is calculated. To the total amount of air thus found 20 per cent. is to be added for contingencies. In order to provide storage for this quantity of air, it is usually the practice to compress it until the tank pressure is from four to six times that which will be used in the cylinders.

All tank fittings are screwed into flanges of cast steel, which are riveted to the body of the tanks, and in this way a good thread hold is obtained and the tank stiffened at that point.

The tanks rest on a steel locomotive frame from which the weight is transmitted by means of springs and equalizers to the journals of the driving wheels.

52. Auxiliary Tanks.—From the high-pressure tanks of the locomotive, the air is taken into an **auxiliary tank** before it is allowed to enter the locomotive cylinders. This tank is a section of wrought-iron pipe with closed ends about two-thirds of the length of the high-pressure tanks and 8 or 9 inches in diameter. It is placed in a convenient position parallel with the storage tanks. Its object is to hold air at a reduced pressure to be used directly in the cylinders. By means of an automatic reducing valve and stop-valve, the pressure in the auxiliary reservoir is adjusted to the requirements of the engines.

53. The Working Pressure.—From the auxiliary tank, the air passes through a throttle valve to the cylinders. The pressure in the auxiliary tank, which is called the **working pressure,** varies from 125 to 150 pounds per square inch.

54. Reasons for Reducing Cylinder Pressure.—The reduction of the storage-tank pressure permits of the maintenance of a constant working pressure in the cylinders; prevents the waste of air that would be likely to ensue if air at full storage-tank pressure were admitted to the cylinders, and makes the locomotive more manageable. The cylinders, moreover, need not be made so heavy as would be required for the high pressure direct from the storage tanks. This reduction in pressure is obtained by the use of a reducing valve, which may be quickly adjusted to regulate the pressure in the auxiliary tank.

55. Automatic Reducing Valve.—In order to maintain a uniform pressure at the throttle valve, a uniform pressure must be maintained in the auxiliary storage tank of the locomotive. This is accomplished by a special reducing valve that works automatically and feeds just sufficient air to the auxiliary tank to maintain a steady pressure. This valve is shown in Fig. 10. It consists of a double-seated balanced valve and an actuating piston controlled by the air pressure in the auxiliary tank and a spring so adjusted that the two regulate the air supply. The air pressure in the auxiliary tank acts [illegible] piston, tending to close the valve. This action [illegible] adjusted to hold the valve off the seat until the maximum allowable pressure in the auxiliary tank is reached, when the pressure of the air overcomes the spring and the valve closes.

56. The Stop-Valve.—It is important to have valves, called **stop-valves,** between the auxiliary tank and the cylinders to prevent any leakage of air by the throttle to the cylinder when the former is closed. This valve is necessary,

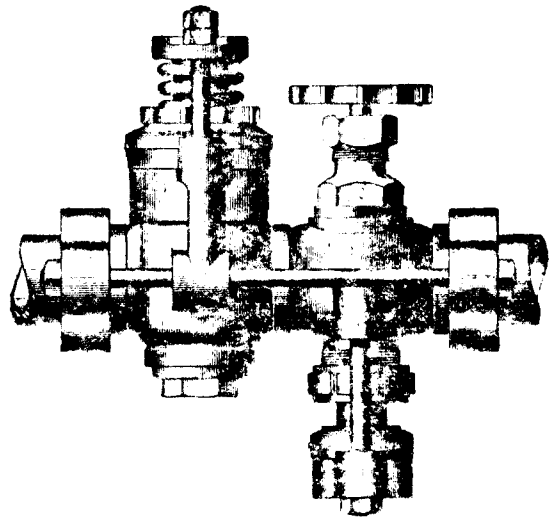


Fig. 10

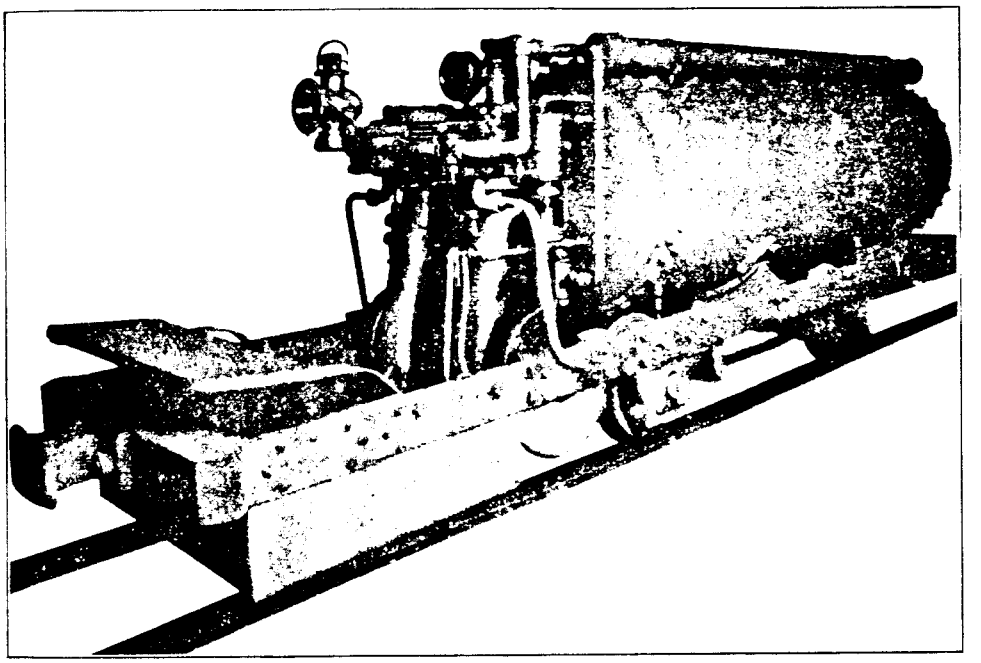
as any leakage of air would make it impossible to keep the locomotive at rest. For additional precaution, a single-seated stop-valve is sometimes placed between the storage reservoir and the reducing valve; this valve is controlled by the lever that controls the throttle valve. When the latter is open the stop-valve is open, thus admitting air to the auxiliary tank only as air is drawn from that for the cylinders. On some locomotives, stop-valves are only placed between the auxiliary tank and the cylinders.

57. Reheating Compressed Air.—The efficiency of compressed air can be greatly increased by reheating before admitting it into the cylinders, but the added complication of the locomotive machinery needed to reheat the air is seldom justified in haulage machinery by the saving in fuel or increased efficiency of the locomotive, except in special cases where a very long mileage must be made or where the price of fuel is very high.

Compressed air used in locomotive cylinders may be reheated by being passed over hot water in the auxiliary tank. The water, which partly fills the tank, is kept hot by injecting steam into the tank while the locomotive storage tank is being charged. The air, as it passes on its way to the cylinders, is compelled to pass over this water and is thus heated. Indirectly this is another cause for increased efficiency, as the moisture taken up by the air in this way affords better lubrication in the valves and cylinders. Compressed-air cylinders should not be lagged with non-conducting covering, as is so necessary for steam cylinders to minimize condensation. By exposing the surface of the cold cylinders to the warm air of the mine, some heat is absorbed and added energy is imparted to the compressed air. Sometimes, the exterior surface of the cylinders is cast with corrugations, in order to present the largest possible surface to the warm surrounding air of the mine.

58. Use of Compressed Air Expansively.—The air is sometimes admitted to the cylinders throughout nearly full stroke, and consequently, as the exhaust is at high pressure, the efficiency is lower than it should be. This practice is doubtless due to the tendency to use as small a motor as possible for the service required, on account of the limited headroom and narrow crooked gangways so common in mines. Better economic results are obtainable, however, by using the air expansively and increasing the size of the locomotive and the weight on the drivers; this is almost always done with large locomotives. Ample reserve power is available when necessary, since full tank pressure can be admitted to the cylinders in starting a heavy load, or in pulling on steep grades and sharp curves.

In using the air expansively, as can be done with properly proportioned cylinders, there should be no trouble from freezing of the moisture. Although the cold developed will produce a low cylinder temperature, yet, as the initial working pressure is so much higher than that employed for pumps and other compressed-air machinery, the expanded air becomes relatively dry, and the force of the exhaust will still be sufficient to keep the ports clear of accumulated ice. To this end, the exhaust ports should be large, straight, and short. If the high-pressure air from the main tank were used in the engines, both pistons and cylinders would have to be made excessively heavy, and any reasonable degree of expansion would produce a degree of cold difficult to deal with.



A Narrow-Gage Compressed Air Tunnel Locomotive.

A NARROW GAGE COMPRESSED AIR LOCOMOTIVE

The half-tone shows a locomotive designed by Mr. E. A. Rix of San Francisco, who has done much to promote the use of compressed air, especially by novel and original applications of it. Three of these locomotives have been made for a tunnel over three miles long which is being built near San Francisco. The tunnel is being driven from each end and in both directions from a central shaft, thus providing work for the three locomotives. The gage of the locomotive is 20-inch and its weight about 7,000 pounds. It passes through an opening 34 inches wide and 50 inches high. It will haul 12 tons at a speed of 6 or 7 miles an hour, and a charge of air is sufficient for a mile and return. The maximum pressure in the storage tank is 1,000 pounds and a pressure reducer maintains 100 pounds as the working pressure. The engine is, of course, reversible, although the link motion is not used, and there are air brakes and all the necessary fittings for handy and safe operation. A chain drive connects the engine shaft with the axles.

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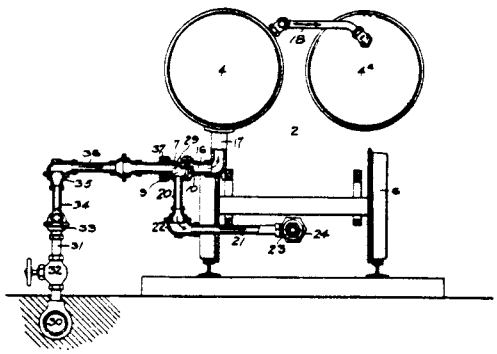
U. S. PATENT OFFICE.

OCTOBER 20, 1908.

901,617. APPARATUS FOR CHARGING LOCOMOTIVES. CHARLES B. HODGES, Pittsburg, Pa. Filed Apr. 27, 1908. Serial No. 429,460.



1. In apparatus for charging compressed air locomotives in tandem, the combination with a supply pipe, of reservoirs, flexible pipe connections between said reservoirs, means for connecting up said connections with said supply pipe, means for cutting off said reservoirs from said connections, and means for releasing the pressure from said connections.

2. In apparatus for charging compressed air locomotives in tandem, the combination with a supply pipe, of reservoirs, flexible pipe connections between said reservoirs, check-valves controlling the supply to said reservoirs, and means for releasing the pressure from said pipe connections when said check valves are closed.

3. In apparatus for charging compressed air locomotives in tandem, the combination with a supply pipe, of reservoirs, check-valves, freely releasable connections between one of said check-valves and said supply pipe, flexible pipe connections from one check-valve to the other, connections between said check-valves and said reservoirs, and means for releasing the pressure in said flexible pipe connections.

4. In apparatus for charging compressed air locomotives in tandem, the combination with a supply-pipe, of reservoirs, check-valves, connections between said check-valves and said reservoirs, flexible pipe connections between said check-valves, freely releasable connections between said supply-pipe and one of said check-valves, and a bleeder-valve to release the pressure from said flexible pipe connections.

5. In apparatus for charging compressed air locomotives in tandem, the combination with a supply-pipe, of reservoirs, check-valves, connections between said valves and said reservoirs, flexible pipe connections from the supply side of the casing of one of said check-valves to the supply side of the casing of the other valve, the supply opening of one of said casings being closed, means for connecting up the other casing to said supply-pipe, and means for releasing the pressure from said flexible connections before or at the time that said locomotives are disconnected from said supply-pipe.

TANDEM COMPRESSED AIR LOCOMOTIVES

The Baldwin Locomotive Works have recently built eight compressed air locomotives for the H. C. Frick Coke Company, a pair of them being shown in the half tone. These engines are alike except that six of them have a track gage of 3 ft 6 inches and the other pair 3 feet 4 inches. They are for a gaseous mine where the employment of electricity would be dangerous, the operating conditions requiring the hauling of heavy loads up grades as steep of 5 per cent. and around curves of 180 feet radius. The restricted clearance limits made it practically impossible to design a single locomotive meeting the conditions, so they were arranged to be operated in tandem as here shown.

The locomotives are coupled back to back, one operator controlling the two units by a single throttle lever, reverse lever, brake valve, etc., the locomotives also being charged simultamously by means of a flevible connection between the air tanks. This flexible connection is closed when the locomotives are in operation, but the auxiliary, working pressure tanks are then in communication through a rubber hose, so that the cylinder pressures on the two units are equalized. This pressure is maintained by the reducing valves at 150 lbs., the initial pressure in the storage tanks being 800 lbs.

Each locomotive is provided with two air tanks, one of which is about 30 inches shorter than the other to allow room for the operator. They are built of steel plates 7/8 inch thick, being 31 3/4 inches in diameter, and the longest 14 feet 9 1/4 inches long. The circumferential seams are triple riveted and welded, and are further reenforced by an inside liner secured to the shell by eight rows of rivets.

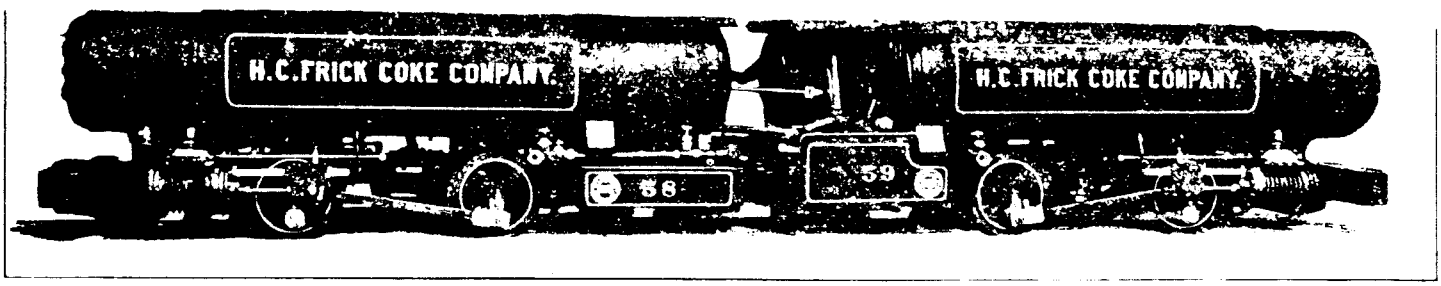
The details of construction, as far as frames, running gear and valve gear are concerned, present many features similar to those of the steam locomotive practice. The frames are of cast steel, of the usual bar form in the middle and narrowed down to a slab section at each end. The air tanks are supported on cast steel saddles, one of which is bolted between the slab frames at each end of the locomotive. The cylinders, 8 by 12 inch, are cast separately and are placed outside the frames. The driving wheels are 4 feet 6 inches diameter, the combined weight of the two locomotives is 46,400 pounds, and as the normal traction force is 8,160 pounds, a liberal factor of adhesion is assured. The equipment throughout is most complete for a locomotive of this type, and special attention has been given to making the coupling devices simple and positive in action so that the locomotives can be readily operated in tandem.

COMPRESSED AIR MAGAZINE. October 1908

DEATH OF GARDNER D HISCOX

Gardner Dexter Hiscox was born at Elizabethtown, N. Y., in 182[illegible], and died at East Orange, N. J., on Sept. [illegible], 1908. He was in many respects an exceptional [illegible] observing of more than a passing [illegible] for a consecutive narrative of his career does not seem to be accessible. Born on Lake Champlain and amid rural surroundings he had no more than the usual education obtainable in the district school and the village academy of his time, which, however, afforded facilities for practical preparation for life's activities not to be spoken lightly of even to-day. Before he was out of his teens he was teaching school and soon thereafter he engaged in mercantile pursuits which he followed most of his active life. He was in business in Chicago when the fearful panic of 1857 occurred and brought his career to a close there. His longest consecutive business connection is understood to have been as a partner in a house in New York, manufacturing and dealing in steam and water fittings and supplies, and he became an expert and a leading authority upon steam heating, ventilation and sanitary engineering. His later years were spent in consulting and advisory engineering, in editorial work and in compiling technical books. He was connected with the Scientific American for many years and is understood to have been especially engaged there in conducting the technical question and answer department, for which he was eminently qualified. He was also a contributor to the Compressed Air Magazine from the first year of its existence. Mr. Hiscox was the victim of a serious trolley car accident some six years ago, which practically confined him to his residence for the rest of his days.

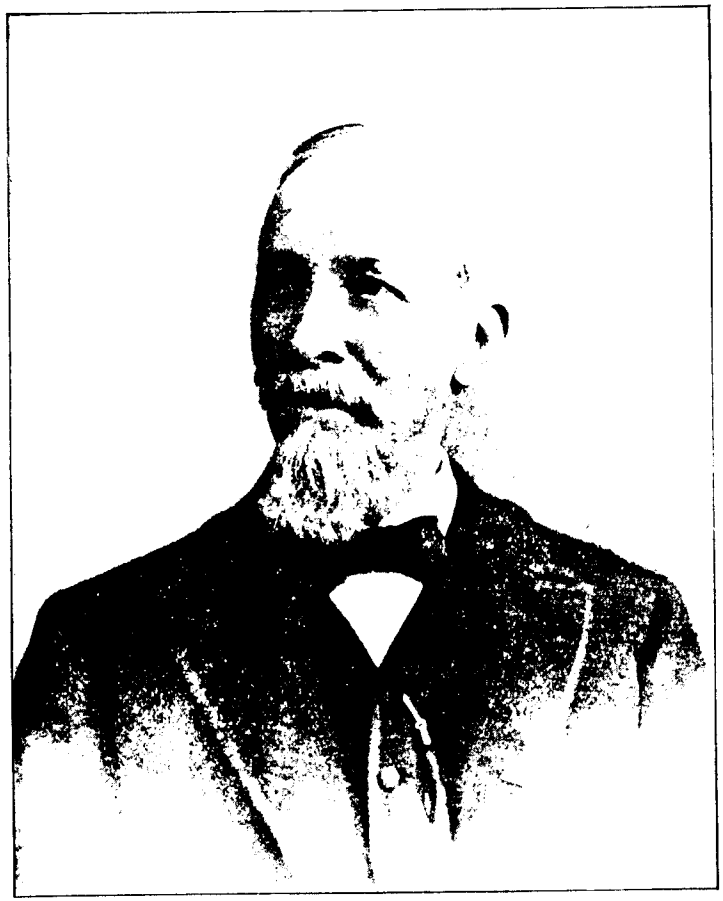
Mr. Hiscox was a man of exceptional and tireless mental activity. He perhaps had no special hobby, but he was an omnivorous collector of all available information in every line.



TANDEM COMPRESSED AIR LOCOMOTIVES FOR COAL MINES.

He seemed to know much about everything and he was always glad to communicate anything that would help anybody. He was besides all else an amateur mechanic with a workshop of choice tools in which he spent many leisure hours with results of lasting excellence and value. He had an exceptionally fine microscope which he had built and a valuable collection of objects of his own preparation. He had also built a telescope and in connection with that he became incidentally the founder of the Brooklyn Astronomical Society.

The most enduring work of Mr. Hiscox is of course in his books. These, in the range of them, indicate the reach and versatility of the man. If any are disposed to speak of them as compilations rather than works of original and independent research and deduction, they must at least concede that the work he undertook to do in them was thoroughly done and they are of lasting value. The titles of his books are as follows: "Mechanical Movements," "Mechanical Appliances," "Gas, Gasoline and Oil Engines," "Twentieth Century Book of Recipes, Formulas and Processes," "Modern Steam Engineering," "Compressed Air in All Its Applications," "Hydraulic Engineering."



Yours Truly
Gardner D Hiscox

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Its Production, Uses, and Applications

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By GARDNER D. HISCOX, M.E.

Author of "Mechanical Movements, Powers, Devices, and Appliances," "Gas, Gasoline, and Oil Engines," etc., etc.

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FIFTH EDITION, REVISED AND ENLARGED

NEW YORK

THE NORMAN W. HENLEY PUBLISHING CO.

132 NASSAU STREET

1909

Compressed air for street railways was continually agitated by newspapers and promoters during the middle of the nineteenth century. But little practical progress was made, much of the difficulties and obstructions being due probably to the distrust of the moneyed interest of schemes that had no practical and reliable tests and trials.

In 1862 the writer made plans for a light car street-railway system with compressed-air storage under the seats and on top of the car, with the engine under the platform, so that the passenger accommodation was not interfered with. The air pressure of two hundred and fifty pounds was to be supplied from station storage tanks and a compressor on the line. The plans did not meet with financial encouragement, and proved to be premature. The horse was not yet ready to go. Another generation was needed to bring compressed-air power for railways to a financial acceptance.

FIG. 402.—COMPRESSED-AIR MOTOR PASSENGER CAR, ON SECOND AVENUE, NEW YORK. 1879-80.

Chapter XXV.

COMPRESSED AIR IN RAILWAY SERVICE.

IT is now forty years since compressed air for street-railway propulsion was agitated and began to take on form in plans for putting this system into practical operation. Although high air pressures had then and previously been produced in an experimental way, the high-storage pressures of the present time were then scarcely dreamed of for practical work. The air-propulsion schemes seem to have slumbered until Captain Beaumont started a compressed-air passenger car with rising storage pressures that finally reached 1,000 pounds, at which the conditions of receiver construction for storage seemed to have reached a limit. At this time (1876), Mekarski was advocating and putting into practice, in France, the system of reheating by hot water and using the evaporated water at high temperatures with the air, and on this system mine-hauling locomotives were operated. The first air-motor car was run in Paris in 1876. This was soon followed by the building of compressed-air railways at Nantes, the suburban roads of Vincennes and Nogent near Paris. In 1890 the Berne, Switzerland, city and suburban railways were opened for operation. The storage pressure there used was 470 pounds, while the car-storage pressure was limited to 440 pounds per square inch. An extended investigation of the operating expenses of this road was made at that time, and was found very favorable to the compressed-air system, being 17 cents per car mile.

The conclusions derived from the investigation of the Mekarski system at Berne for urban and suburban tramway traffic consisted in the pleasing appearance of the motor cars, in the absolutely smooth and noiseless motion, and the total

absence of smoke, steam, or heat; that it had fully vindicated this system as preferable to any other system of tramway traction. At Marseilles, France, the compressed-air tramway storage pressure is 1,200 pounds per square inch.

The reheaters of this system are illustrated in the chapter on reheating. The Hardie system was first on trial on the Second Avenue Railroad in 1879 (Fig. 402).

This system was started in Toledo, Ohio, and in Westfield, Mass., about 1892, but from some constructive difficulties was changed to electric propulsion.

The Judson system was originally instituted in a revolving drum under the track, driven in sections by compressed-air motors with air compressed in a central station and distributed to the motors through an underground pipe system. This failing in expectations, the Judson system was changed to direct motor traction with the air heated by a small furnace containing a coiled pipe near the motor, in which the air was reheated after passing the reducing pressure valve, thus giving the best effect of reheating in the economy of air power.

This system finally gave way to the Hardie improvements on the Mekarski system, and is now in use in Chicago, Ill., with passenger motor cars, with or without trailers to suit the necessity for traffic accommodation.

In Fig. 406 are represented some details of these motor cars, in which the piston in the cylinder H is connected by rod with a rock shaft for transferring the line of force to the outside of the wheels through the connecting rod P pivoted to the parallel-rod connection to the fore and aft wheel cranks. L is the brake cylinder, and F one of the high-pressure bottles. M M are columns in which are placed the controlling gear with their handles at N.

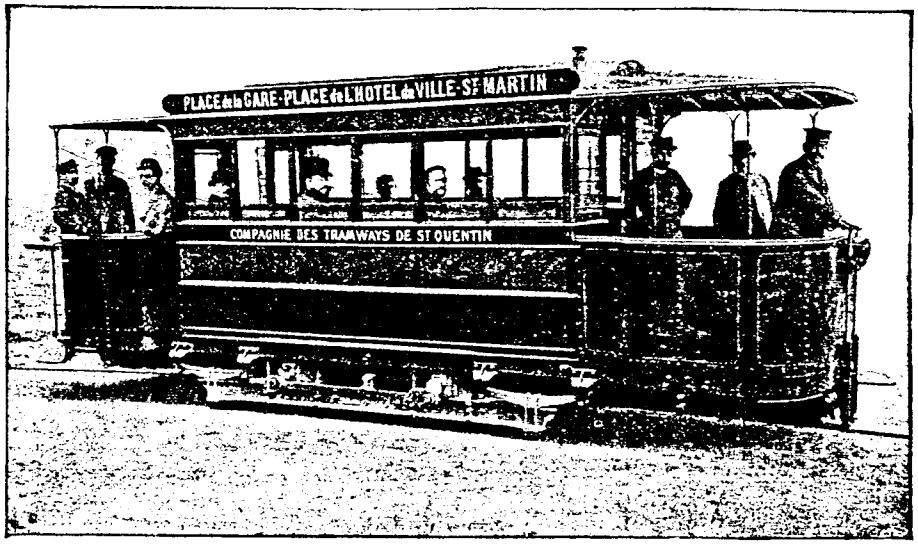


FIG. 403.—COMPRESSED-AIR MOTOR CAR, ST. QUENTIN TRAMWAY CO., FRANCE. MEKARSKI SYSTEM.

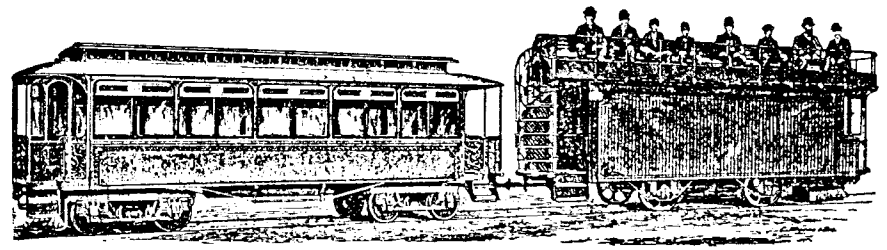


FIG. 404.—THE JUDSON SYSTEM IN CHICAGO, ILL. MOTOR PASSENGER CAR AND TRAILER.

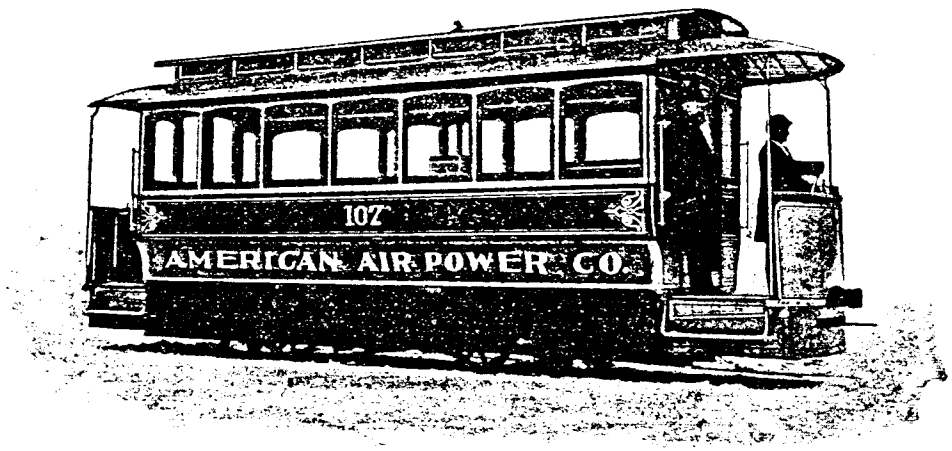


FIG. 405.—COMPRESSED AIR MOTOR CAR ON 125TH STREET, NEW YORK CITY.

Storage capacity of car, 51 cubic feet at 2,000 pounds pressure per square inch. Working pressure 150 pounds, reheated by hot water at 300° F., initial temperature. Expansion in cylinders at near atmospheric pressure without noise. These cars have a mileage of from 14 to 20 miles per charge of air, according to condition of track and traffic.

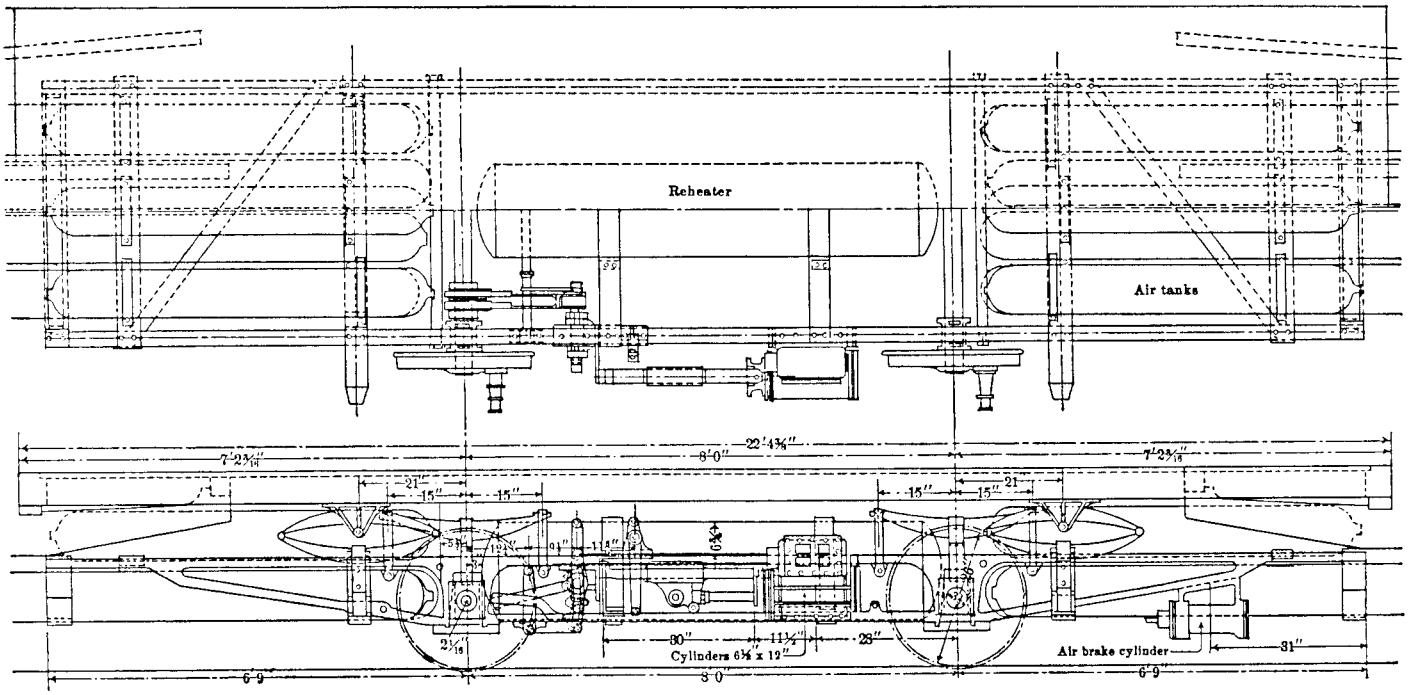


FIG. 409.—DETAILS OF RUNNING AND MOTOR GEAR.

Hardie Motor System, 28th and 29th Streets, New York City.

In Fig. 407 is illustrated a section of the Hardie motor car of the type used on 125th Street, New York City, showing the location of the high-pressure air tanks *B*, *C*, *D*, *E*, *F*, and the reheating tank *A*; the reducing valve at *G* and the motor cylinder at *H*. The air passes from the high-pressure tanks to the reducer, then to the reheater, discharging beneath the water and taking on its temperature, and is saturated with vapor at a pressure of 150 pounds; then to the controlling valve and expanded in the cylinders to near the atmospheric pressure under normal conditions of running. In Fig. 408 is an indicator card from

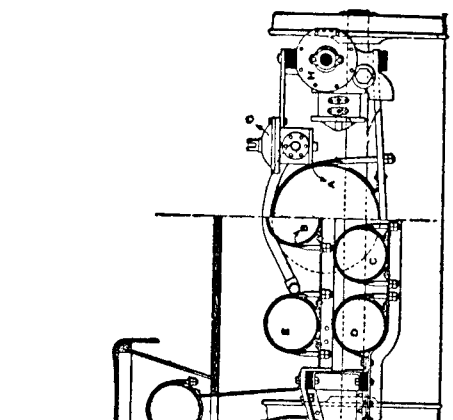


FIG. 407.—SECTION, HARDIE MOTOR CAR.

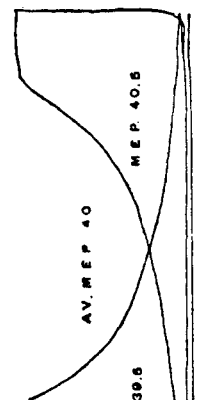
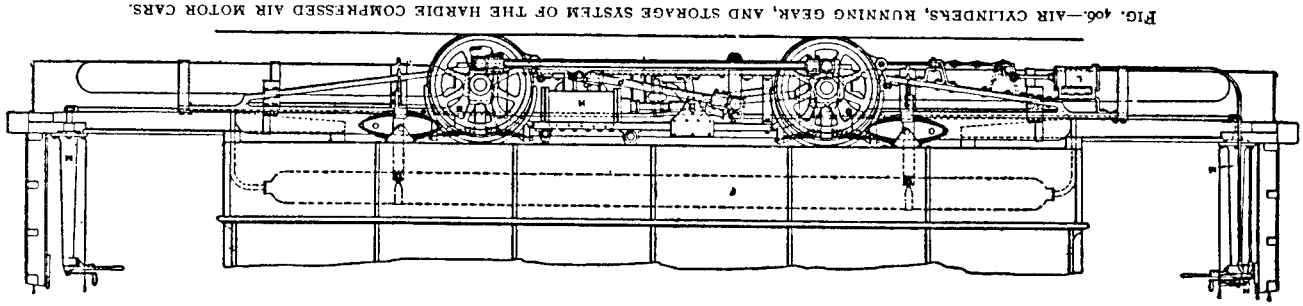


FIG. 408.—THE AIR-PRESSURE CARD.

FIG. 406.—AIR CYLINDERS, RUNNING GEAR, AND STORAGE SYSTEM OF THE HARDIE COMPRESSED AIR MOTOR CARS.



these motors showing a mean pressure of about 40 pounds at $\frac{1}{8}$ cut-off.

In Fig. 409 are detailed a plan and elevation of a Hardie motor car, the various parts of which may be measured by the figured scale of the elevation, and in Fig. 405 an outside view of the same style of car now running on the 28th and 29th Streets line of the Metropolitan Railway Company, New York City. Similar cars are running on the street railway system at Rome, N. Y.

The motor cars of the COMPRESSED AIR COMPANY, New York City, are similar, in size and appearance, to standard electric or cable cars, and can be operated at any desired speed. The type of car now in operation weighs about 22,000 pounds. All its machinery and storage apparatus are placed below the body proper. The motor and storage are supported and carried on independent frames and springs which relieve the axle of all pounding and hammering on the track.

The engines of these cars have two cylinders, 7-inch diameter, 14-inch stroke, with driving-wheels of 16-inch diameter. They are equipped with air brakes operated by the same air that runs the motors. The operating levers are placed on the platforms, are simple in form, and of such design that no confusion can arise in the manipulations of the operator.

The storage apparatus consists of sixteen air reservoirs, having a total capacity of 51 cubic feet and weighing 4,340 pounds. One of these is placed under each seat, running the entire length of the car. The others are arranged beneath the floor of the car, and all of them rest on a framework of locomotive construction supported on the usual type of locomotive springs. The framework also supports a heater 7 feet long and 19 inches in diameter that contains 500 pounds of hot water, through which the air passes on its way to the motors.

This type of car has run 17 miles on one charge of air, but is rated as having a capacity of 12 miles, anything over that being reckoned as margin to allow for emergencies, heavy

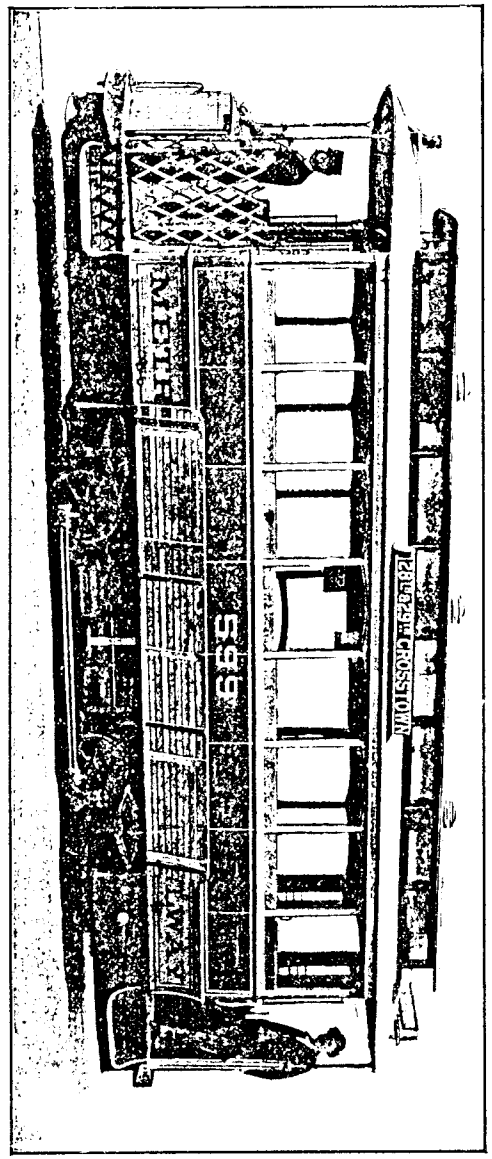


FIG. 410.—COMPRESSED AIR MOTOR CAR OF THE METROPOLITAN STREET RAILWAY CO., 28TH AND 29TH STREETS, NEW YORK CITY. HARDIE MOTOR SYSTEM.

Car 32 feet over all; seats 30 passengers; weight of truck and motor, 11,000 pounds; total weight, 19,000.

loads, frequent stops, bad tracks, etc. Its normal speed is 12 miles an hour, but, like the steam locomotive, it can be operated at any required speed.

In Fig. 411 are detailed the proportions of the reheater used in the cars of the Metropolitan line, 28th and 29th Streets, New York City. It will be seen that the air after pressure reduction to the working limit, 150 pounds, is delivered to the reheater through a perforated pipe lying on the bottom of the cylinder and beneath the hot-water surface. Baffle plates are placed across the cylinder to prevent the water from swashing on starting and stopping the car. A perforated pipe *T* along the top of the cylinder conveys the air, reheated at the reduced pressure, to the throttle valve on the platform and from thence to the cylinder.

In Fig. 412 is shown the elevation and end view of the motor gear with an outside cylinder connected directly with the crank pin on the wheel. The other wheel is connected by an extension of the wheel crank pins and an outside connecting rod. The rocker arm *g* is operated by a link *l*, pivoted to the slide and oscillating on the pivot *p*, fixed to the frame and also connected by a link to the arm *f*, which is pivoted to the cut-off valve at *m*, and to an extension of the wrist pin on the double rocker arm *a*, which is operated by a sector slide linked to cams on the wheel shaft; so that the main valve and cut-off have variable motion in both forward and backward running.

It is apparent from Fig. 413 that the reducing valve is a diaphragm valve, specially constructed to deal with high pressure, and that, in addition to the ordinary action of such valves, a supplementary action is brought about by reducing the air pressure that is normally kept above the valve head in chamber *A*. In ordinary action this valve graduates air to 150 pounds. When it is desired quickly to accelerate under heavy load, a movement of the brake-valve handle to a given position discharges the air from chamber *A*; this increases the value of the coil spring beneath the diaphragm, opening the reducing

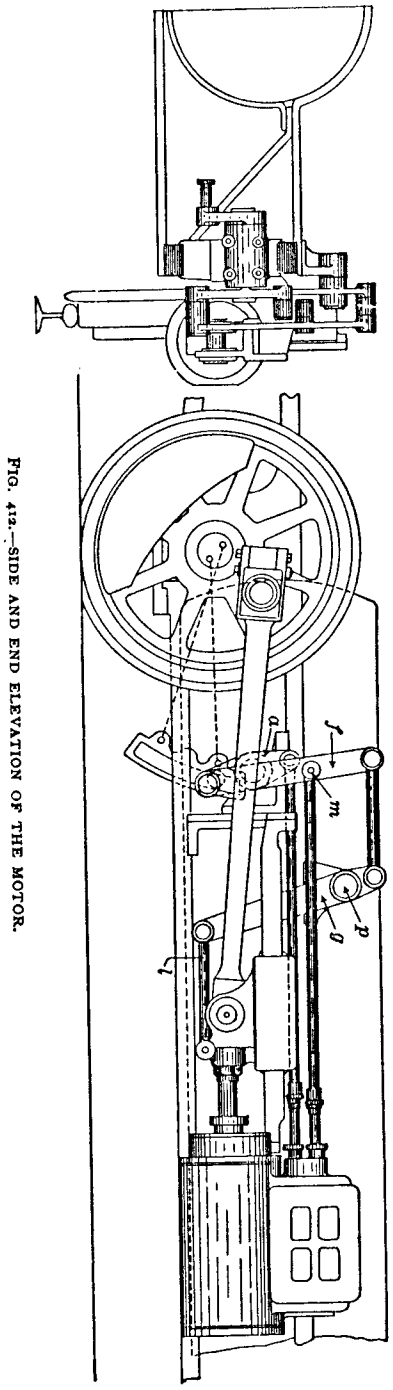


FIG. 412.—SIDE AND END ELEVATION OF THE MOTOR.

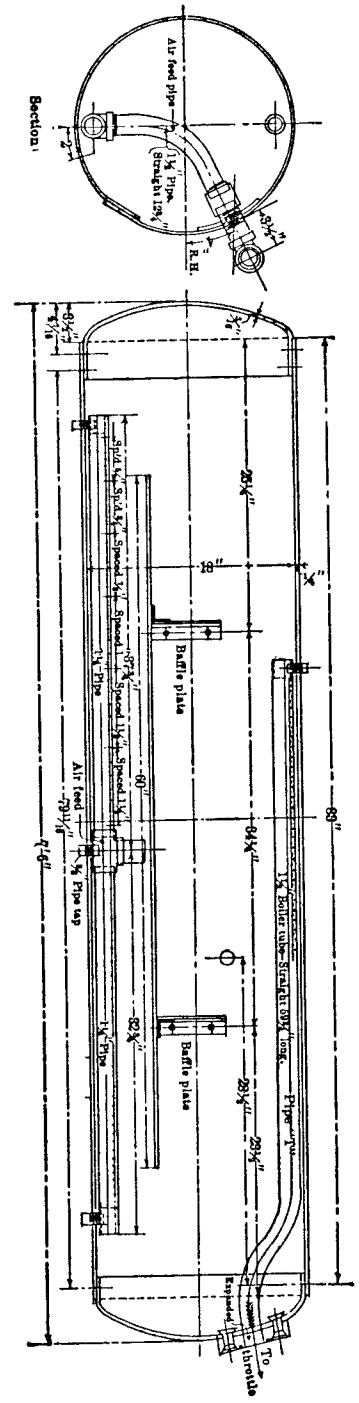


FIG. 411.—DETAILS OF THE REHEATER. HARDIE AIR MOTOR.

valve in greater measure, and temporarily increases the working pressure to 200 pounds per square inch, while it is desirable to use that pressure in the cylinders.

Fig. 414 illustrates the operation of the air brake of the

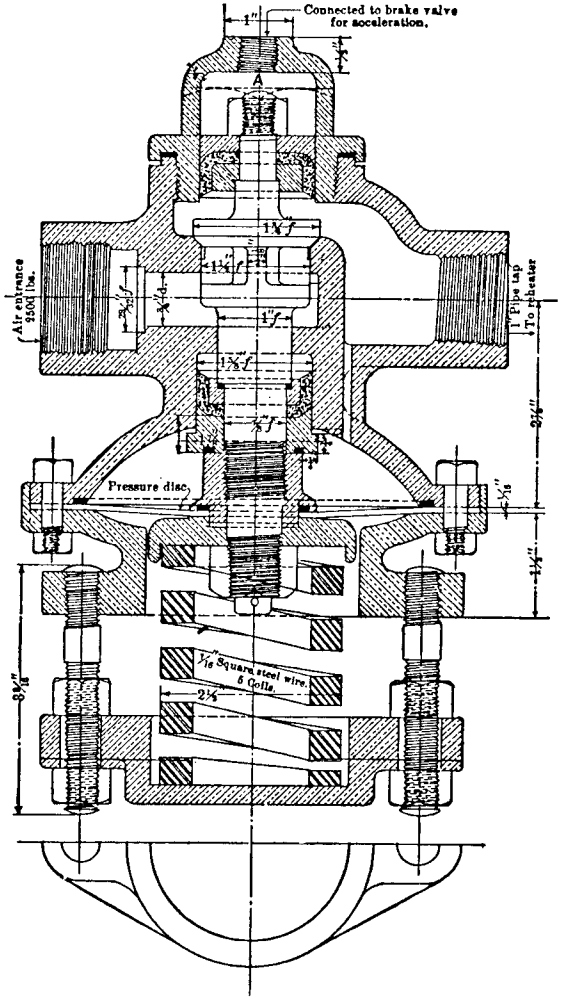


FIG. 413.—DETAIL SECTION OF REDUCING VALVE.

Hardie motor car. The brake piston rod is hollow, and thus forms a cylinder within the brake cylinder.

In the illustration the piston is shown in the set position, and the motorman's brake valve would be in service application. Braking force is applied by admitting air to the annular space marked *R*. When release is made the air passes from the point *T* through a by-pass and the release valve to the point *V* in the rear of the piston, and pressure is thus exerted upon the greater area of the total diameter of the piston head. The

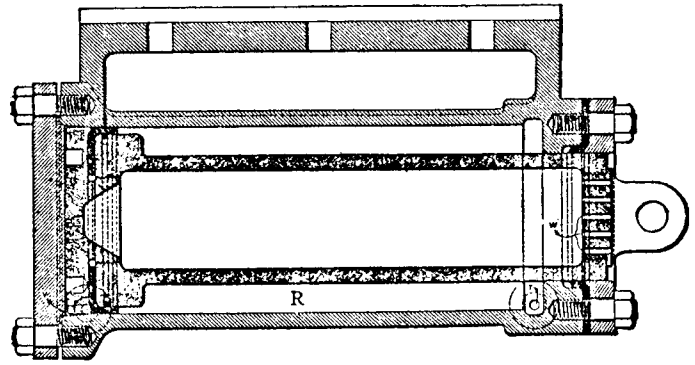


FIG. 414.—THE BRAKE CYLINDER.

difference in pressure area will therefore restore the piston to the release position and the air, thus applied in releasing, bleeds through the opening *S* and out of the hollow piston through numerous ports, *W*, to atmosphere, the bleeding action being so free as to be practically noiseless.

The first compressed-air locomotive for Iona Island, N. Y to furnish motive power for cars containing ammunition, under contract with the United States Government, has been completed at the H. K. Porter Locomotive Works. It is the type of locomotive decided upon for moving railroad cars about the vast magazines which are the storehouses for ammunition used in the coast defences and forts throughout the country. The engine now finished is a novel one, and was ordered together with a complete plant for charging and operating.

In event of the new locomotive proving a success and standing the tests that it will be put to, the Government will order a number of others like it, all to be used on the same island. Iona Island is probably the greatest storehouse for explosives that is owned by the United States. It is situated in

the Hudson River, a short distance from New York, and from it ordnance and ammunition are sent out to the various points along the coast. For a long time the handling of explosives has been done with mules, dragging cars and carts. It has been a slow and tedious process, as well as a costly one. The island is covered with a series of railroad tracks, and cars from the West Shore Railroad are used in shipping material, being loaded and moved about by teams. It is absolutely necessary that there should be no fire of any kind near the storehouses of the ammunition.

The success that attended the use of compressed-air locomotives in the great plant of the California Powder Company, near San Francisco, drew the attention of the army officials to the availability of compressed-air traction for Iona Island, and after much planning the first plant was ordered. This consists of

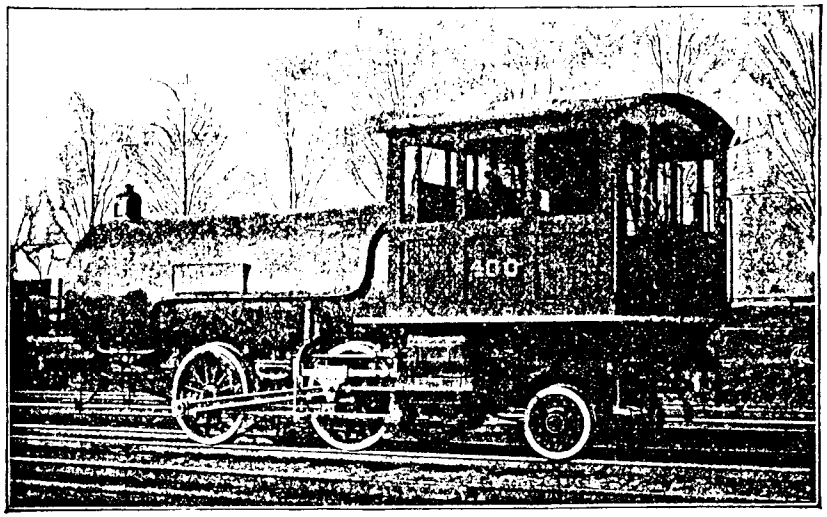


FIG. 415.—THE HARDIE COMPRESSED-AIR LOCOMOTIVE.

one locomotive capable of handling standard railroad cars, a series of charging stations along the lines of the rails for charging the locomotives whenever it is necessary, and a complete power plant for operating the compressors.

The new locomotive is said to be one of the largest of its kind ever built. It will run several miles without being recharged, and can be charged with air at any one of the numerous stations in less than thirty seconds. There being no fire of any kind about the locomotives, there is not the least danger from explosion.

THE COST OF COMPRESSED-AIR RAILWAY SERVICE.

From the few compressed-air railways in which the entire plant has been built for a specific amount of service, accurate returns of cost of operating as compared with the same service of other systems of locomotion have been meagre and unsatisfactory.

The cost of operating the air plant on the Nantes, France, railway has been stated at 12 cents per car mile. It is fifty-eight miles in length and has gradients of four per cent.

The cost of operating the air plant on the Berne, Switzerland, tramway has been given as 17 cents per car mile. The road is two miles or more in extent and has gradients of over five per cent, necessitating heavier power motors than for lower grades.

On the 125th Street line in New York the compressed-air cars were switched in between the cable cars and were limited to their regular speed, not being favored by conditions for clean runs. The frequent stops made necessary by city traffic counted against the best conditions for cost of service, and made the volume of air used larger than for a less obstructed service. The steepest grade on this line is 7.7 per cent, which for only a short run necessitates, as stated for the Berne plant, a heavier motor power than for more even grades. The cars actually operated on this line were two; but the installation was made for a larger number, which brought the operating cost to an excessive figure, viz., 20 cents per car mile. On the basis of a larger number of cars, suitable for the compressed-air installation, the cost has been estimated at less than 17 cents per car mile. With the

improvements of service now being done the cost should fall to about 13 cents per car mile. The average consumption of free air per car mile on the 125th Street line has averaged during seven months' service 477 cubic feet per car mile. The operation of the air cars on the 28th and 29th Streets line has not yet given sufficient data in regard to cost, as the compressing plant largely exceeds the present needs of the car plant.

It has been estimated that the actual cost of compressing air to 2,500 pounds pressure per square inch, and storing for use in a modern air-compressing plant operated with condensing engines, including coal at $2.75 per ton, water at $1 per 1,000 cubic feet, oil and waste, the removal of ashes, labor, repairs, and maintenance of power plant, depreciation and interest on cost of entire power-plant including buildings, for compressing plants of the following capacities, based on the consumption of $2\frac{1}{2}$ pounds of coal per hour per horse power for twenty hours per day, will not exceed the following figures:

Cost per 1,000 cubic feet of free air compressed to 2,500 pounds pressure per square inch:

Station capacity.	Cost.	Station capacity.	Cost.
500 cubic feet per minute....	$0.0675	6,000 cubic feet per minute....	$0.0359
1,000 " "	.0571	7,000 " "	.0342
2,000 " "	.0469	8,000 " "	.0326
3,000 " "	.0419	9,000 " "	.0312
4,000 " "	.0394	10,000 " "	.0300
5,000 " "	.0375		

Responsible parties will guarantee that the cost will be less than stated, and the writer believes that the cost in highest-grade plants can be reduced fully 25 per cent. from the above figures.

COMPRESSED AIR FOR UNDERGROUND HAULAGE.

The use of compressed air for underground haulage was probably given its first practical application in the St. Gothard tunnel in 1873 and on, until the tunnel was finished. The initial pressure then used was only 210 pounds in the main tank, reduced to a working pressure of 60 pounds in the secondary tank. High pressures had not then entered the realm of the practical use of compressed air; but the early pneumatic locomotives did good work. The modern application of compressed air in mine haulage is exemplified in the operation of pneumatic locomotives in the mines of the Susquehanna Coal Company at Glen Lyon, Pa., where there are two compressed-air motors in operation. The air is supplied by a compressor of the three-stage type, having steam cylinders 20 x 24 inches and air cylinders $12\frac{1}{2}$ x $9\frac{1}{2}$ and 5 x 24 inches, with water-jackets and intercoolers, compressing the air to 600 pounds per square inch. The air passes through a line of 5-inch special strong pipe 200 feet to the head of the shaft, down the shaft 800 feet, and then along the gangway about 3,400 feet, a total length of 4,300 feet. This pipe line has a capacity of 580 cubic feet and acts as a reservoir for the compressor. It is coupled together with threaded sockets which are counterbored for a lead filling, which is calked. At intervals of about 200 feet, and at all valves and charging stations, flange couplings are used with lead gaskets. The line is perfectly tight, being tested to 1,500 pounds per square inch. Charging stations are placed where required, and consist of a universal metallic coupling which is attached to the check valve of the locomotive air tanks when a fresh supply of air is required. It requires about one and one-half minutes to complete the operation of charging the locomotive, and reduces the pressure in the main pipe line from 600 pounds per square inch to about 570 pounds per square inch. A charge of air weighs about 380 pounds. The locomotive is of the four-wheel type, having cylinders 7 inches diameter by 14-inch stroke; drivers, 24 inches diameter; weight, 18,500 pounds; length over all, 17 feet 6 inches; width, 5 feet 2 inches; height, 5 feet. The air for propelling the locomotive is stored in two cylindrical steel tanks with a combined capacity of 130 cubic feet and supported by cast-iron saddles resting on the frames of the locomotive. The air flows from the main tanks through a

specially designed reducing valve into an auxiliary reservoir, and from thence through a throttle valve to the cylinders. The pressure in the auxiliary reservoir can be regulated anywhere from 30 pounds up to 140 pounds or 150 pounds per square inch as required. The air in the auxiliary reservoir is maintained at a constant pressure, while in the main storage tanks it may vary from 570 pounds per square inch down to the pressure at which the reducing valve is adjusted; when this pressure is reached in the main storage tanks the air passes through to the cylinders without further reduction in pressure.

The locomotive hauls sixteen empty cars a distance of 3,700 feet into the gangway and returns to the shaft sixteen loaded cars with one charge of air, starting with a pressure of 575 pounds per square inch and ending with about 100 pounds per square inch. The train of empty cars, including the locomotive, weighs 60,000 pounds, and the train of loaded cars, including the locomotive, weighs 166,000 pounds. The grades favor the loads. The locomotive runs from twenty-five to fifty miles per day, depending upon the length of trip and time consumed in making up the trains at the terminals. This locomotive was lowered down the mine shaft a vertical distance of 800 feet without dismantling in any manner.

PNEUMATIC MINE LOCOMOTIVES OF THE BALDWIN LOCOMOTIVE WORKS.

The new modification of the pneumatic locomotives of this company is shown in Figs. 416 to 419, an advance in air-motor design in the ribbed compound cylinders.

Pneumatic locomotives for mine haulage have been in use for several years, and are to-day a standard product of all the large steam locomotive builders. They possess several features which make them ideal for mining purposes and most suitable for quite a variety of surface work, generally industrial operations, such as plantations, tunnels, powder mills, lumber yards,

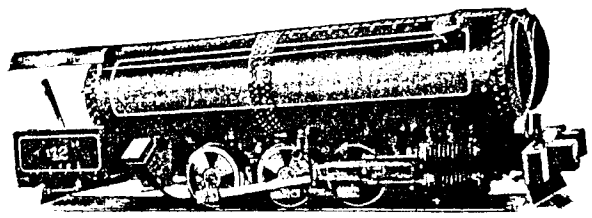


FIG. 416.—COMPOUND PNEUMATIC LOCOMOTIVE.

Six-wheel type. Compound cylinders, ribbed for the absorption of heat from the outer air, thus preventing extreme cold in the exhaust. Built for the H. C. Frick Coal Company.

textile manufactories, cotton mills, storage warehouses, and other places where the risk of fire resulting from sparks and the freedom from other objectionable features make the compressed-air locomotive a most desirable and satisfactory means of hauling.

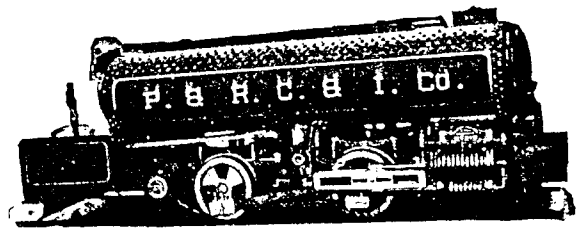


FIG. 417.—COMPOUND PNEUMATIC LOCOMOTIVE.

Four-wheel type. Ribbed cylinders. Built for the Philadelphia and Reading Coal and Iron Company.

Compressed-air power has marked advantages over any other kind of haulage power for mines and constructive works, where

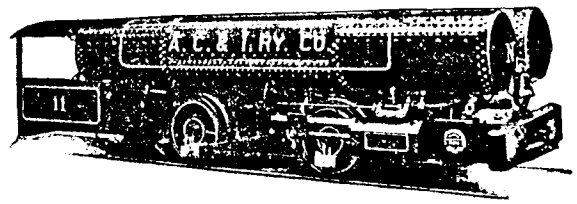


FIG. 418.—PNEUMATIC MINE LOCOMOTIVE.

Two-cylinder, four-wheel type.

the entanglements of electric wires and stays are always in the way, and steam is a nuisance. Compressed-air power is a free traveller to go wherever a track is laid and even without tracks

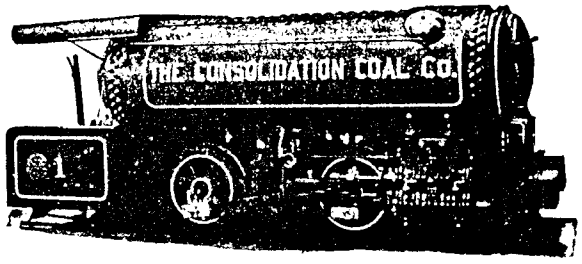


FIG. 419.—SINGLE-TANK PNEUMATIC LOCOMOTIVE.
Baldwin Locomotive Works.

in the compressed-air driven truck. The distance run with one charge of air is only limited by the capacity of the storage tanks, and since high initial pressure has become available, the limit of usefulness has been largely extended.

COMPRESSED-AIR LOCOMOTIVES FOR HAULAGE.

The mule, which has so long been used for hauling in mines and in yard work, has nearly lost his calling by the successful adoption of the more powerful agent, compressed air, in the

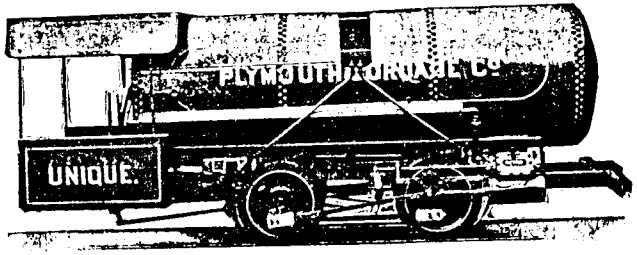


FIG. 420.—PNEUMATIC LOCOMOTIVE FOR YARD AND FACTORY SERVICE.

diminutive narrow-gauge locomotive that needs no feed when no work is being done. The compressed-air system has entirely supplanted steam in underground work, and has become a most economical competitor of both steam and electricity in yard and factory haulage.

Fig. 421 represents a type of yard locomotive of the H. K. Porter Company, Pittsburg, Pa., designed for factory and yard work. It is built for narrow gauge and with wheel base as short as 3 feet 6 inches, and for curves of 12 feet radius. The single air tank carries a maximum pressure of 600 pounds per square inch, with an auxiliary reservoir from which the motors are operated at not more than 140 pounds pressure. This style of compressed-air locomotive is made in twelve

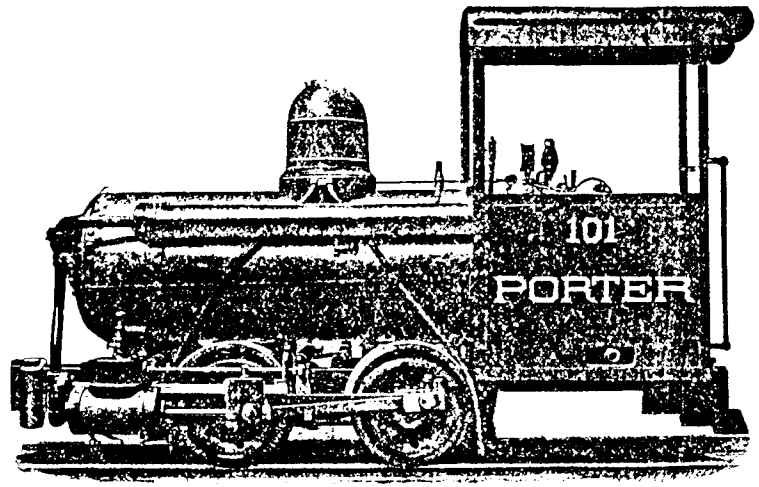


FIG. 421.—INDUSTRIAL PNEUMATIC LOCOMOTIVE.

sizes, the smallest having motor cylinders 4 x 8 inches; the largest, 11 x 14 inches.

The larger locomotives built for the longer runs required on plantations and for shipping heavy goods from iron works and factories are also made in twelve sizes with air-storage capacity of from 45 to 260 cubic feet of compressed air at from 600 to 700 pounds pressure.

A Contrast in Locomotives.

The accompanying photograph shows three locomotives—all modern, all built by the same maker—and yet presenting a striking contrast in size, design and general appearance. It is an extreme illustration of modification of design due to the different conditions and requirements under which a machine is to be used.

The large steam locomotive (really of only moderate size) is of the six-wheel switcher type with an eight-wheeled tender. Its principal dimensions are as follows:

Cylinders, 20-in. dia., 26-in. stroke; driving wheels, 56-in. dia.; weight of engine, 150,000 lbs.; weight of tender, 90,000 lbs.; rigid wheel base of engine, 11 ft.; height, 14 ft. 6 ins.; width, 9 ft. 10 ins.; length over bumpers, 30 ft. 3 ins.; tractive force, 35,300 lbs.; boiler, straight type; diameter, 72 ins.; pressure, 200 lbs.; firebox, 96 × 39 ins.; 328 tubes, 2 ins. in dia., 11 ft. long; total heating surface, 2,029 sq. ft.; grate area, 26 sq. ft.; tender capacity, 4,500 gals. water, 7 tons coal; standard gage.

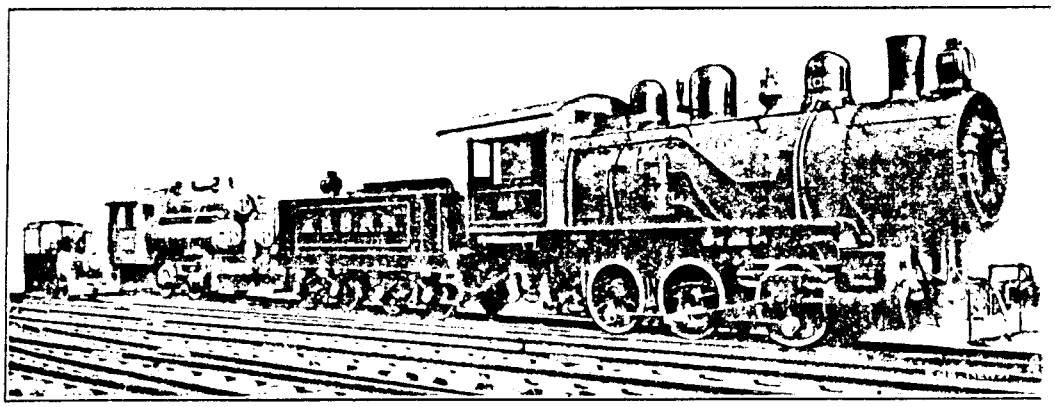
Just behind the switch engine is a compressed-air locomotive, which is claimed by the H. K. Porter Co.,* maker of all three engines, to be the largest two-stage air locomotive in the world. It was built for use at a powder magazine and is designed to start five loaded freight cars on a level track and to haul two loaded steel coal cars five miles on a single charge of air. It is of the four-wheel type with a main reservoir consisting of three tanks all connected together. The tanks are 40-ins. in diameter, two 15 ft. long and the third 17 ft. in length. The principal dimensions follow:

H.P. cylinder, 11 × 18 ins.; L.P. cylinder, 22 × 18 ins.; wheels, 36-ins. dia.; rigid wheel base, 5 ft. 9 ins.; weight of engine, 55,000 lbs.; capacity, main reservoir, 375 cu. ft.; tractive force, 10,000 lbs.; height, 12 ft. 0 ins.; width, 9 ft. 6 ins.; length, 21 ft. 11 ins.; pressure at throttle, 250 lbs.; L. P. cylinder pressure, 50 lbs.; main reservoir pressure, 825 lbs.; standard gage.

The small locomotive at the left of the picture was built for use on a private plantation railway in Nicaragua. It is of the four-wheel type with side tanks and a steel-canopy cab. Its chief dimensions are as follows:

Cylinders, 5 × 10 ins.; driving wheels, 20-in. diameter; rigid wheel base, 3 ft. 6 ins.; height, 8 ft. 0 ins.; width, 5 ft. 4 ins.; length, 10 ft. 2½ ins.; weight of engine, 11,000 lbs.; tractive force, 1,700 lbs.; boiler, straight type; diameter, 23 ins.; pressure, 160 lbs.; firebox, 26 ins. × 18½ ins.; 37 tubes, 1½ ins. diam.; 3 ft. 2 ins. long; heating surface, 58.9 sq. ft.; grate area, 3.34 sq. ft.; capacity of tanks, 150 gals.; capacity of fuel box, 200 lbs. coal; gage, 30 ins.

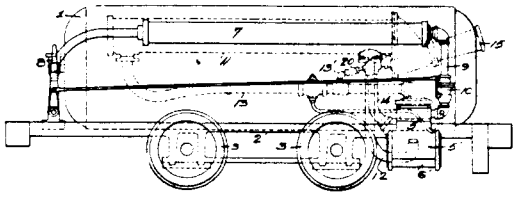
It appears from these data that the plantation locomotive could probably pull the 75-ton switcher along a level track, providing that the switcher were willing.



A 75-TON SWITCH ENGINE, A LARGE COMPRESSED-AIR LOCOMOTIVE AND A DIMINUTIVE STEAM LOCOMOTIVE FOR PLANTATION USE.

U. S. PATENT OFFICE. MARCH 29, 1910.

953,334. METHOD OF OPERATING COMPOUND COMPRESSED-AIR ENGINES. CHARLES B. HODGES, Pittsburg, Pa., assignor to H. K. Porter Company, Pittsburg, Pa., a Corporation of Pennsylvania. Filed June 11, 1909. Serial No. 501,641.



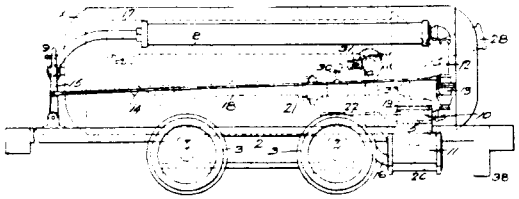
1. The method of operating compressed air engines, consisting in carrying the air at high pressure through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature, re-heating the exhaust air from said cylinder when confined by extended exposure to air heating at atmospheric temperature and thereby increasing the volume thereof and its capacity to generate power, and carrying the re-heated air through a low pressure cylinder.

2. The method of operating compressed air engines, consisting in carrying air at high pressure through one cylinder and thereby reducing it below atmospheric temperature, confining such air within a receptacle and by a jet of air under pressure inducing a current of air at atmospheric temperature over the exposed surface of such receptacle and thereby reheating and increasing the volume of such exposed air, and carrying the reheated air through a low pressure cylinder.

3. The method of operating compressed air engines, consisting in carrying the air at high pressure through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature, re-heating the exhaust air from said cylinder when confined by extended exposure to air heating at atmospheric temperature and thereby increasing the volume thereof, and carrying the re-heated air through a low pressure cylinder, and so discharging the exhaust therefrom as to induce a draft over the exposed surfaces of the receptacle confining the exhaust air from the high pressure cylinder.

4. The method of operating compressed air engines, consisting in carrying the air at high pressure through and expanding it in one cylinder and thereby reducing it below lowest atmospheric temperature and re-heating the exhaust air when confined by extended exposure thereof to air at atmospheric temperature and thereby increasing it to the necessary volume to generate substantially like power within another cylinder of greater cubical contents and carrying such re-heated air through such low pressure cylinder.

953,335. METHOD OF OPERATING COMPOUND COMPRESSED-AIR ENGINES. CHARLES B. HODGES, Pittsburg, Pa., assignor to H. K. Porter Company, Pittsburg, Pa., a Corporation of Pennsylvania. Filed June 11, 1909. Serial No. 501,642.

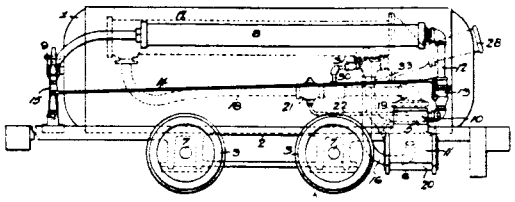


1. The method of operating compound compressed air engines, consisting in carrying the compressed air at high pressure and expanding it within one cylinder and thereby reducing it below atmospheric temperature, confining such exhaust air from said cylinder within a receptacle and inducing over the exposed surfaces of said receptacle a violent current of air at atmospheric temperature sufficient to scour from or prevent the formation of frost on the exposed surfaces of said receptacle and thereby reheating and increasing the volume of such exhaust air and its capacity to generate power, and carrying the reheated air through a low pressure cylinder.

2. The method of operating compound compressed air engines, consisting of carrying the compressed air through and expanding it within one cylinder and thereby reducing it below atmospheric temperature, confining such air within a receptacle having a series of tubes passing through the same and inducing a violent current of air at atmospheric temperature through the tubes of such receptacle sufficient to scour from or prevent the formation of frost therein, thereby reheating and increasing the volume of such exhaust air and carrying the reheated air through a low pressure cylinder.

3. The method of operating compressed air engines, consisting in carrying the air at high pressure through one cylinder, confining the exhaust air therefrom within a receptacle having extended exposed surfaces and then through a low pressure cylinder, and inducing a current of air at atmospheric temperature over the surfaces of the confining receptacle by a jet of air at as high pressure as that entering the low pressure cylinder.

953,336. COMPRESSED-AIR ENGINE. CHARLES B. HODGES, Pittsburg, Pa., assignor to H. K. Porter Company, Pittsburg, Pa., a Corporation of Pennsylvania. Filed June 11, 1909. Serial No. 501,643.



1. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, said inter-heater having a long contracted body of small diameter filled with a large number of tubes of small diameter, and means for inducing a current of atmospheric air through said tubes sufficient to cause a scouring draft through the said tubes and prevent the formation of frost thereon.

2. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, an inter-heater between them having large exposed surfaces and having a nozzle on the discharge end thereof, an air jet communicating with said nozzle and a pipe carrying air under pressure as high as that entering the low pressure cylinder and communicating with said air jet.

3. In a compound compressed air engine, the combination of a high pressure cylinder, a low pressure cylinder, an air inter-heater, a pipe leading from the exhaust of the high pressure engine to said inter-heater, and a pipe leading from said inter-heater to the low pressure cylinder, and a pipe leading from said latter pipe to supply air under pressure to produce the current of air over the exposed surfaces of the inter-heater.

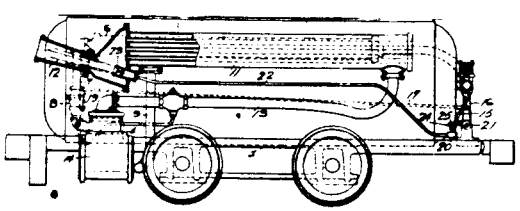
4. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, an inter-heater, a pipe leading from the high pressure engine to the inter-heater and a pipe leading from the inter-heater to the low pressure engine, said pipe having a stop valve located therein, and a pipe connected to said pipe between the stop valve and the low pressure engine for supplying air under pressure to produce a draft over the exposed surfaces of the inter-heater.

5. In a compound compressed air engine, the combination of a high pressure engine, a low pressure engine, an inter-heater between them having a discharge nozzle and an air jet to induce a draft over the exposed surfaces of the inter-heater, a pipe carrying air under pressure as high as that entering the low pressure cylinder and leading to said air jet and a pipe leading from the exhaust of the low pressure engine to said air jet.

DECEMBER 20, 1910.

U. S. PATENT OFFICE.

979,165. COMPOUND COMPRESSED-AIR ENGINE. CHARLES B. HODGES, Pittsburg, Pa., assignor to H. K. Porter Company, Pittsburg, Pa., a Corporation of Pennsylvania. Filed June 11, 1909. Serial No. 501,639.



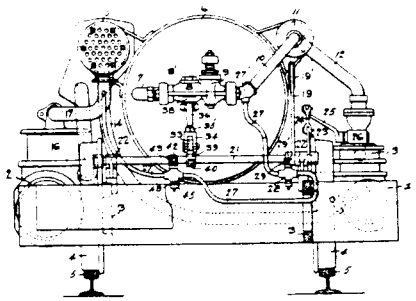
1. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine and an inter-heater between them, a main throttle valve, means for inducing a current over the exposed surfaces of the inter-heater, a valve controlling the same and a lever controlling both the main throttle valve and the current inducing valve.

2. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, a main throttle valve, an air jet nozzle for inducing a current over the exposed surfaces of the inter-heater, an air jet valve for feeding air under pressure to said nozzle, and a lever controlling both the throttle valve and the air jet valve.

3. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, a throttle valve and a throttle lever controlling the same, means operated by air under pressure for inducing a current over the exposed surfaces of the inter-heater, and a valve controlling the current inducing means located close to the throttle lever and operated thereby.

4. In compound compressed air engines, the combination of a high pressure engine, a low pressure engine, and an inter-heater between them, means operated by air under pressure for inducing a current over the exposed surfaces of the inter-heater, and a valve controlling said inducing means, a throttle valve, and a throttle lever connected to the throttle valve and having an auxiliary arm controlling the current inducing valve.

1,024,778. COMPRESSED-AIR ENGINE. CHARLES B. HODGES, Pittsburgh, Pa., assignor to H. K. Porter Co., Pittsburgh, Pa., a Corporation of Pennsylvania. Filed July 31, 1911. Serial No. 641,506. (Cl. 230—35.)



1. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve controlling said connection ahead of said throttle valve, of a low pressure cylinder a by-pass leading from said connection between said valves to said low-pressure cylinder, a valve controlling said by-pass, a throttle lever, and mechanism directly movable thereby to simultaneously open said throttle valve and close said controlling valve.

2. In compressed air engines, the combination with an air reservoir, a high presssure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a normally operative valve controlling said by-pass, and mechanical means controlling said throttle valve and arranged to directly open said last mentioned valve when the throttle valve is closed, and to insure its closing when the throttle valve is open, substantially as described.

3. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a manually operative valve in said by-pass, another valve controlling said by-pass, a throttle lever connected to said throttle valve, and mechanical means closing said first aforementioned valve in said reservoir connection, and opening said last mentioned valve controlling said by-pass when said controlling lever is moved to close said throttle valve, and opening said by-pass connection when said throttle lever is oppositely moved.

4. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a throttle lever controlling said throttle valve, a shaft actuated by said lever and provided with a finger, and a valve controlling said by-pass and opened by said finger when the throttle valve is closed.

5. In compressed air engines, the combination with an air reservoir, a high pressure cylinder, a connection leading from said reservoir thereto, a throttle valve in said connection and another valve adapted to close said connection ahead of said throttle valve, of a low pressure cylinder, a by-pass leading from said connection between said valves to said cylinder, a rotary shaft, a throttle lever carried thereby and controlling said throttle valve, means carried thereby operating said first aforementioned valve, two valves arranged in said by-pass, the first of which is manually operative, and a finger carried by said shaft arranged to open the second of which valves when the throttle valve is closed, and to permit its closing when the throttle valve is open.

[Claims 6 and 7 not printed in the Gazette.]

COMPRESSED-AIR MACHINERY

One characteristic of the ordinary plain displacement pump is the waste of power entailed by the direct release of the displacing air volume after the fluid is rejected from the pump tank. This air, after doing its work, is still at practically full pressure, therefore having all its potential energy of expansion. Its direct exhaust into the atmosphere after displacement is the throwing away of this expansive power without any useful effect.

If the air pipes from the compressor to the tanks are carried back to the compressor room to apply the pressure remaining in the air volume after displacement on the reverse side of the compressor piston, where it would help in compressing the air into the pump tank, we have a "return-air" expansive displacement pump, operating at good economy.

This system has all the advantages of simplicity that the non-expansive system enjoys, with the additional advantage of being much more efficient. Under normal conditions it is safe to say that the "return-air" system will show an average efficiency of 50 to 55 per cent, this efficiency being the ratio of horse power of water lifted to indicated horse power in the steam cylinder of the compressor, including all losses.

COMPRESSED-AIR ENGINES

The question of using compressed air in engines is not one involving any intricate calculations to determine the feasibility of such a practice. Any engine that will operate with steam will operate with compressed air without any changes. Compressed air is used, however, only in small units and principally in hoisting engines on temporary construction work.

The volume of air required in an engine depends on the cut-off, varying directly with it as does the horse power. Hence, for a given pressure, the horse power of an engine determines the amount of air used. Too often air is used non-expansively in engines, and in this case the volume of air used is the volume swept through by the piston with an additional 10 per cent for leakage.

The following table shows the volume of air required for operating hoisting engines under working conditions, the air being delivered to the engine at 60-pounds gauge pressure. In this table the hoisting engine is supposed to run but half the time while the compressor works continuously. If the engine runs less than half the time, as it usually does, the air required will be proportionately less, and *vice versa*. The table is computed for maximum loads, which also vary widely in practice. Because of the intermittent character of the work of a hoisting engine the parts are able to resume their normal temperature between the hoists, and there is little probability of annoyance due to freezing up the exhaust passages.

TABLE OF THE VOLUME OF FREE AIR REQUIRED FOR OPERATING HOISTING ENGINES

The air compressed to 60 pounds gauge pressure.

Cyl. dia. in inches	Stroke inches	Revs. per minute	Nominal H. P.	Actual H. P.	Weight lifted single rope	Cu. ft. free air per min.
5	6	200	3	5.9	600	75
5	8	160	4	6.3	1,000	80
$6\frac{1}{4}$	8	160	6	9.9	1,500	125
$8\frac{1}{4}$	10	125	15	12.1	2,000	151
7	10	125	10	16.8	3,000	170
$8\frac{1}{2}$	12	110	20	18.9	5,000	238
10	12	110	25	26.2	6,000	330

The table given above is for single-cylinder engines. For double-cylinder engines of the same diameters and the same speed, the horse powers and the air consumption will be doubled.

Compressed-Air Locomotives

Locomotives particularly adapted for mine haulage were first used in the United States about 1870. These early locomotives were operated by steam, and proved vastly more efficient and economical than the prevailing system of hauling by animal power. Their use, however, was limited to the main gangways of well ventilated mines on account of the danger and inconvenience from fire and escaping steam and gases. In order to overcome the difficulties attending the use of steam, compressed air was substituted. A reservoir was provided for the reception of the air, to take the place of the steam boiler, making no material change in the arrangement of the machinery, In this way the efficiency derived from the use of the locomotive was retained and danger avoided.

It will be readily seen that locomotives actuated by compressed air can exert only so much power as has previously been stored within them, and when this power has been exhausted it can be restored only from without. It is necessary, therefore, to provide tanks or reservoirs of sufficient capacity to supply the total power demanded for the entire run, or from one charging station to another.

In view of the large quantity of free air required to propel a locomotive when drawing any considerable load, it is of the greatest importance to consider carefully the storage capacity, and to utilize any means

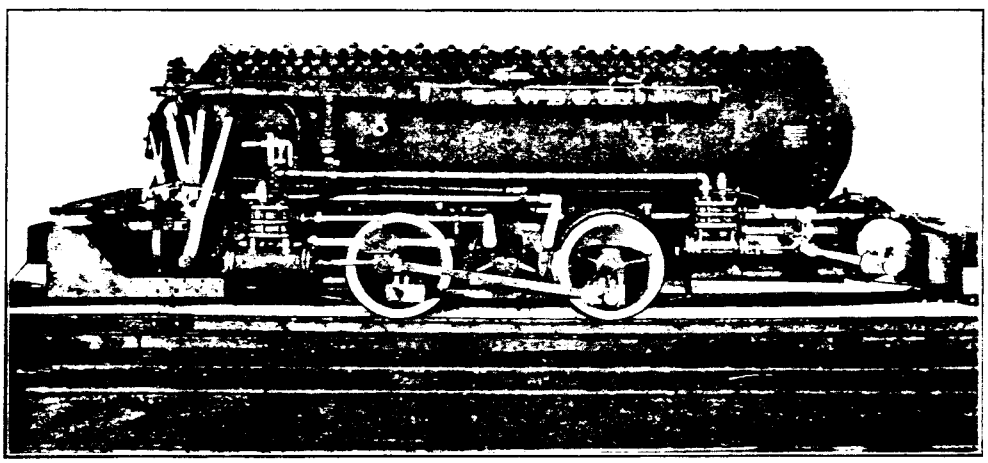


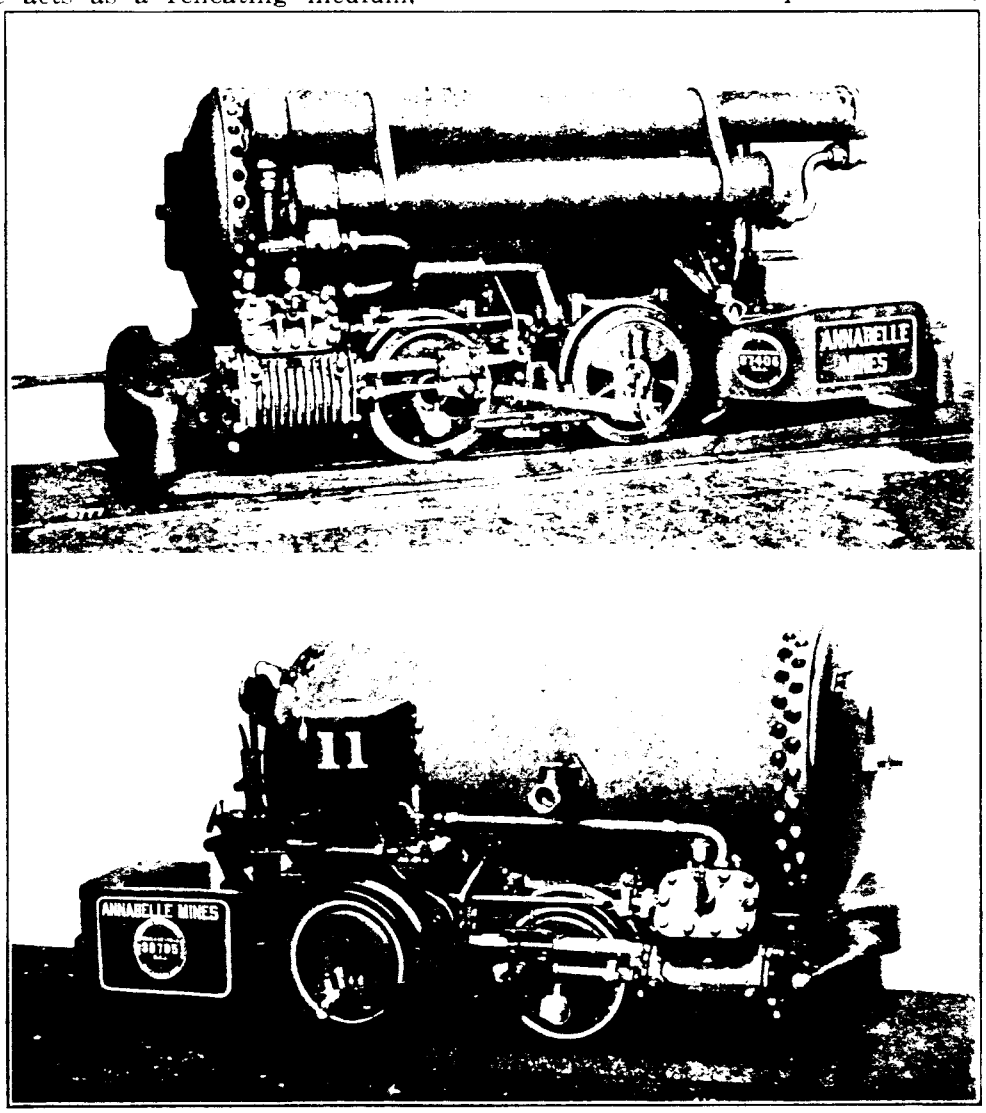
FIG. 85. 18,000-POUND AIR LOCOMOTIVE. BUILT BY H. K. PORTER COMPANY, PITTSBURGH, FOR THE LEHIGH AND WILKES-BARRE COAL COMPANY

The locomotive cylinders are 6 and 12 inches in diameter with a stroke of 12 inches. Hoisting drum has cylinders of equal diameters but 8-inch stroke. Drum is used for hauling cars up steep pitches.

which will economize the air or increase its efficiency, as this directly affects the capacity of the locomotive both for hauling power and for length of run.

When air is expanded in the locomotive a drop in temperature is experienced, reaching far below that of the atmosphere; this has a marked effect on the final volume of the air used in the cylinders. An increase in economy and efficiency will, therefore, be obtained by restoring some of its lost heat. An efficient system of reheating would be highly desirable were it not for the complications involved, and the fact that for mine service the process of reheating brings with it the very danger that the use of the compressed-air locomotive is intended to avoid. Since the outer air is warmer than the expanding compressed air, the atmosphere acts as a reheating medium, and in order to increase the effect of this the cylinders are corrugated to enlarge the reheating surface.

In order to get the effect of reheating without using heat from an external source, the two-stage air locomotive is used. In this type of machine the drop in temperature in each cylinder is much less than it would be if the same expansion occurred in one cylinder. The total drop would be the same, but it is possible to heat the air between the cylinders by means of the atmosphere. This increases the efficiency of the locomotive in addition to doing away with some of the troubles due to extremely low temperatures. The two-stage locomotive will do from 40 to 60 per cent more work with the same quantity of air, thus reducing the cost of power about 30 per cent; reducing the size of compressors and boilers



FIGS. 86, 88. AIR LOCOMOTIVES FOR MINE SERVICE BY THE BALDWIN LOCOMOTIVE WORKS

Above: Compound locomotive; 6- and 12-inch cylinders with common stroke of 10 inches; 800 pounds storage pressure and 250 pounds working pressure; weight, 15,500 pounds.
Below: Single-stage locomotive; 6- by 10-inch cylinders; 800 pounds storage pressure and 140 pounds working pressure; weight, 14,050 pounds.

30 per cent; reducing the first cost of the installation approximately 15 per cent; and increasing by 30 per cent the distance which the locomotive will travel on one charge of air.

In the two-stage locomotive the compressed air is expanded in two successive cylinders, providing for a wider range of expansion, with higher initial and lower terminal pressures, thereby securing many of the advantages which compound cylinders give where steam is used, except that in the case of air there can be no cylinder condensation. The effects of a wide range of expansion in a single cylinder, with the resultant great difference in temperature, are, none the less, of serious consequence, causing as they do a temperature of the cylinder and port walls considerably below that of the incoming air, with initial refrigeration and serious shrinking in volume. In addition to this, which is the principal reason for compounding with steam, there are various other considerations which render the expansion of compressed air in successive cylinders either vastly more advantageous or an utter failure, depending upon whether advantage is taken of the radically different conditions under which the two fluids operate.

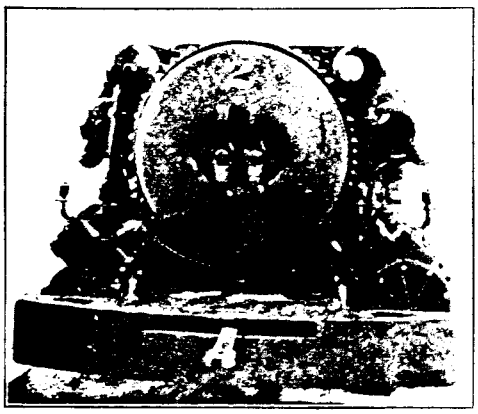
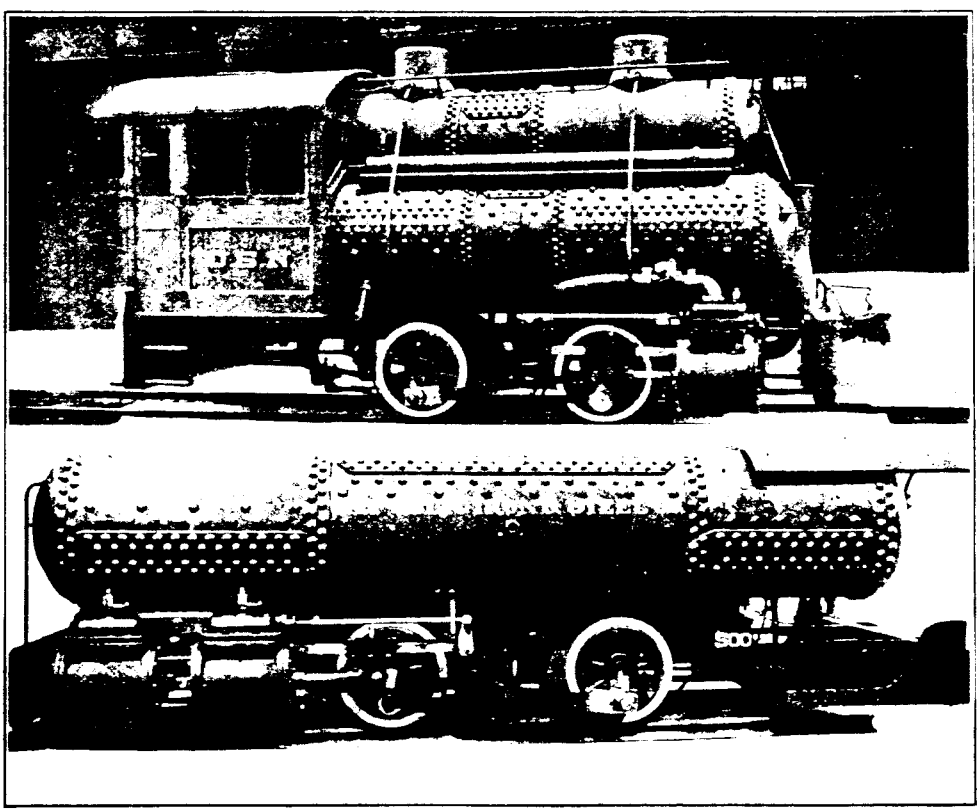


FIG. 87. END VIEW OF FIG. 86, OPPOSITE, SHOWING ATMOSPHERIC INTERHEATER

When air is compressed, the heat of compression is dissipated as soon as possible. If it could be done during compression, then the work of compression would be reduced materially. Much reduction in temperature is accomplished by using two-stage compression and cooling the air between the stages. If the compressed



FIGS. 89, 90. TWO-STAGE AIR LOCOMOTIVES BY THE H. K. PORTER COMPANY

The upper one is in the service of the United States Navy Department, weighs 60,000 pounds. The lower one is a three-cylinder locomotive built for the Republic Iron and Steel Company.

air could be used in a locomotive before the heat of compression is lost, then it would pay to compress adiabatically. Since the compressed air cools in the pipe line, whether or no, the best the locomotive builder can do is to imitate the builder of the two-stage compressors and make his locomotive two-stage. The intercooler of the compressor then becomes the interheater of the locomotive, and it is the interheater that makes the success of the two-stage locomotive.

Since the air entering the high-pressure cylinder of the two-stage locomotive is at atmospheric temperature, and is cooled down by the cylinder walls, it follows that the air which is exhausted after expansion is much colder than the atmosphere. That fact makes it possible to use an interheater without supplying any heat from an outside source, but simply employing the heat of the atmosphere to bring back the temperature of the receiver air to that of the outside air.

Figure 89 illustrates the two-stage locomotive built for the United States Navy and used at Hingham, Massachusetts, for hauling ammunition from the N. Y., N. H. & H. R. R. side track to the magazines and from them to the wharf for delivery to the war ships.

The plant consists of the locomotive, two electrically driven air compressors delivering air at 1,100 pounds pressure, a battery of eight storage tanks, 600 feet of 6-inch pipe, and two charging stations.

In operation, the locomotive is charged to a pressure of 800 pounds in about 2½ minutes and will then travel a distance of about 4 miles, hauling four or five standard freight cars.

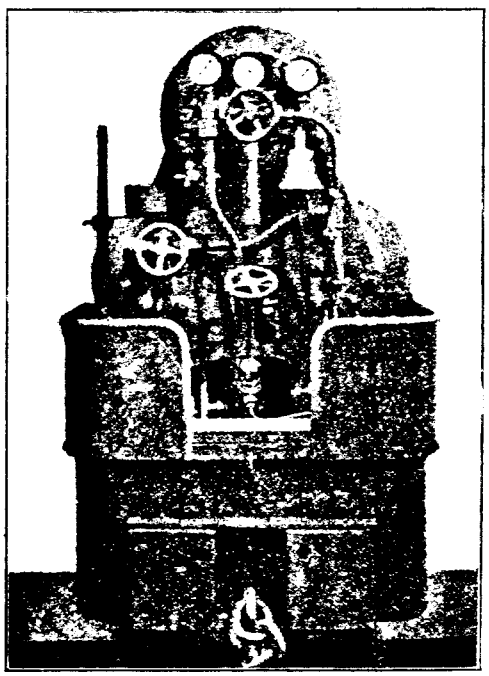
The weight of this locomotive is 60,000 pounds; the cylinders are 11 and 22 inches in diameter, with a common stroke of 18 inches. The tractive force is 10,000 pounds. The regulating valve is set to maintain a uniform pressure of 250 pounds at the throttle.

COMPRESSED AIR TRACTION IN BRITISH COAL MINES

The following is a comparatively brief abstract of an interesting article by Axel Sablin in the Iron and Coal Trades Review.

According to this writer the adoption of compressed air traction in British coal mines is quite recent, but the improvements have followed each other with great rapidity, three periods of development being specifically noted. The first compressors, 1907, were designed for about 1500 lb. pressure. The locomotives had single stage cylinders, their tank pressures were about 750 lb. and the working pressure 150 lb. The reducing valve was one of the specially weak points of these machines. Not more than 4000 yards could be traversed with load without recharging and the cost per ton mile was too high to compete with electric traction.

By 1910, which is noted as the beginning of the second period, four-stage compressors worked up to 2250 lb. The pipes conveying the high pressure air were as small as possible, often 1¼ in., steel flasks were inserted in the line for storage and drainage. The locomotives had three or four tanks which would store the air at nearly full delivery pressure, and reliable reducing valves maintained a constant working pressure of 270 lb. The cylinders were compound with an atmospheric reheater between the high and the low pressure. The exhaust from the low pressure cylinders escaped through a nozzle arranged as



END OF LOCOMOTIVE

an ejector similar to that of the steam locomotive. The remaining energy in the discharged air was thus used to cause a rapid circulation of air in the inter-heater, the low pressure cylinder was prevented from freezing and the admission pressure to the high pressure was thus correspondingly higher than in the older machines. Balanced valves and improved valve gear were adopted, the distance traveled between charges increased to 7000 yards and the air consumption of 1910 was 35 per cent. less than in 1908. Numerous plants were installed and pronounced economically satisfactory, thus encouraging further improvements.

In 1912 another remarkable advance took place. Compressors were built for five stage compression and the delivery pressure was raised to 3000 lb. The locomotives were built with triple expansion engines, using an initial pressure above 400 lb. The high pressure and intermediate cylinders formed a single casting, see Fig. 1. Separate interheaters were arranged between each two cylinders. The traveling distance between chargings, with load, was extended to 10,000 yards. The economy over the locomotive of 1911 was increased by 25 per cent. while the economy of 1908 was improved 55 per cent., so that the air consumption was only 45 per cent. of that of the first locomotives herein mentioned.

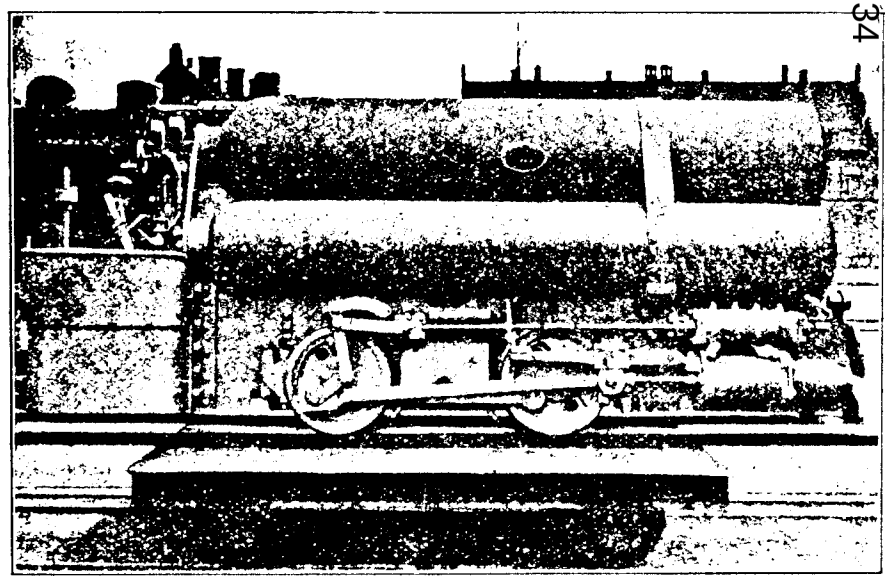
These modern locomotives weigh from 5 to 7½ tons; the gage used varies from 16 in. to 20 in., the minimum curve radius is 26 ft. and the maximum economical grade is 4 ft in 1000 ft. The overall length of the standard locomotive is 13 ft. 6 in., but shunting locomotives are built as short as 10 ft. 8 in. The smallest locomotive is 58 in. high and 36 in. wide; the largest 66 in. high and 40 in. wide. On good track, and with a run of not less than one mile, a locomotive has a proved easily maintained capacity of 250 ton-miles per shift of seven hours. The time of recharging the locomotive in the mine is about 1½ minute, a difference of about 300 lb. being left between the pipe line pressure and the pressure in the locomotive tanks.

The air, before being admitted to the compressor, should be filtered through cloth, the suction chamber having a very large filtering surface. The whole system of air pipes is packed with copper rings ⅛ in. thick, rolled from solid discs. Remarkably tight joints are secured by this method; in fact so perfect that in one instance under observation the drop in pressure in the system during the stop from Saturday to Monday amounted to only 150 lb., or about 6 per cent. of the working pressure.

For filling, the tanks of the locomotives are attached to the compressed air system by flexible drawn copper pipes, packed with the usual copper gaskets. Two filling stations are usually arranged: one at the bottom of the shaft, and another at the locomotive "stables." For lubricating, a special oil is used which remains liquid at —60 deg. C. (—76 F.) A train load usually consists of 40 cars, each carrying 1500 lb. of coal or over a ton of rock. On a good track, however, an air locomotive will haul twice this load.

During the last few years there have been put into service in German colleries many hundreds of air locomotives and close on to a hundred air compressor stations. Other plants are found in operation in Austria-Hungary, in Belgium, in France and in Spain.

The continental compressor works are well employed. In one particular shop were seen, in January of the present year, in various stages of construction, 38 air locomotives and 12 compressors, the largest being a five-stage machine with a capacity of 1,750 cu. ft. of free air per min. compressed to 3,750 lb. This compressor was to be driven by a gas engine.



TRIPLE EXPANSION MINE LOCOMOTIVE.

COMPRESSED AIR MAGAZINE.

August 1914

PNEUMATIC MINE TRACTION

In the June issue of COMPRESSED AIR MAGAZINE we reprinted from Iron and Coal Trade Review an enthusiastically written account of the use of high pressure, triple expansion pneumatic locomotives in European coal mines. It will be remembered that quite extravagant claims were made by the writer as to the economy and efficiency of the system described. The article was in fact written in the spirit of a boy with a new toy and the editor without leaving his desk accepted the story at its face value and without the discounts which are so imperative in such a case.

The new toy feature just alluded to seems to have been especially pronounced in this case. It must be evident that the system so lauded has not yet passed the time test, since the developments spoken of have occurred within a couple of years. The high initial cost of plant, the corresponding maintenance cost, the reliability and safety risks of five stage compressors, excessively high storage pressure and triple expansion locomotives may mark a transition or tentative system rather than one that is finally and generally to be adopted.

For instance, according to the story, the Europeans seem to have discovered the use of compound locomotive cylinders with atmospheric inter-heaters just four years ago, while an American inventor applied for a patent for the same arrangement ten years ago. The possible values of the extremes now exhibited in European practice have been investigated and a mean has been established in this country which is proving highly satisfactory.

The Engineer
October 30, 1914

COMPOUND AND TRIPLE-EXPANSION COMPRESSED AIR LOCOMOTIVES.

THE competition of internal combustion locomotives for underground working has been so keen that the compressed air locomotive appeared likely to be wholly superseded, but this desirable competition has so stimulated the inventive abilities of compressed air locomotive designers that they have quite recently introduced improvements which have resulted in the reinstatement of the air locomotive in important mines. This interesting development in underground traction has been discussed at some length by Mr. M. L. Dehey in the "Annals des Mines de Belgique."

Very often—particularly in Belgian mines—a low first cost has to be preferred to low operating costs, and the petrol motor under such circumstances has a great advantage, since it is independent of a compression plant. But, unfortunately for the "petrol" motor, the price of fuel is continually increasing. In April, 1910, the price of benzine was 18f. per 100 kilos. (£7 6s. 6d. per ton), and in July, 1912, it was 37f. (£15 1s. 2d. per ton). The price thus more than doubled in two years, and there is good reason to believe that it will still rise by reason of the ever-increasing demands being made for liquid fuel. Since 1910 the makers of compressed air locomotives have introduced very important improvements by which the consumption of compressed air has been reduced by the very considerable difference of from 50 to 60 per cent.; first of all, by means of compound expansion, and more recently, by means of triple-expansion working. The price per ton-kilometre with twin-cylinder compressed air locomotives at the Flénu Collieries two years ago was 18 centimes, and if the same plant had, just before the war, been worked by triple-expansion locomotives the price per ton-kilometre would certainly have been less than 12 centimes.

But almost more important than the economy of operation by compounding is the extension of the radius of action after charging. The potential speed is also made greater by these recent improvements, and heavier trains can now be run per ton of engine weight. The speed of the benzine engine is normally 2 m. per second (4.5 miles per hour), and it cannot be modified because the explosion motors run at a constant number of revolutions. This speed is usually selected because it is the maximum admissible on curves or crossings; it might be made considerably more for straight roads and, above all, in ascending inclines where derailments never occur. The mine authorities will not, however, permit higher speed with benzine locomotives, because a derailment at higher speed might cause a burst in the petrol tank and perhaps fire the mine. The speed of 4½ miles per hour is therefore not exceeded, although nothing bars a higher speed with a suitable motor.

With compressed air locomotives the conditions are entirely different, as these engines are found to be as flexible in operation as steam locomotives; their speed can be varied to any extent, and with a good installation it may reach 4 m. per second (9 miles per hour) on the average. The driver runs with full admission on the hills, reduces the speed to a nicety for the curves, and can stop the train dead by reversing the engine. If a derailment occurs at full speed there are no very serious secondary consequences.

In actual working under the same conditions of operating the compressed air locomotive completes its trip in less time than petrol motors. The latter are generally of 12 horse-power, able to haul trains of forty wagons. To use greater power than this would be a disadvantage, because the consumption of benzine becomes excessive when working with light loads. On the contrary, the compound compressed air engines run economically whatever the degree of admission; hence it is economical to use 18 horse-power nominal compressed air engines which can easily develop up to 30 and 35 horse-power. In descending inclines the degree of admission is very low. The engines weigh 6 tons and haul fifty to sixty wagons without difficulty, sand being used to increase the adhesion and to enable the engine to exert its maximum tractive effort in places where the rails are damp.

For these reasons the compressed air engines are found to make a considerably greater ton-mileage than the benzine motors. It is rare that the explosion engine is able to average more than 250 ton-kilometres (156 ton-miles) per shift of eight hours; while 350 ton-kilometres (220 ton-miles) per shift of eight hours are constantly obtained with compound compressed air engines. The coal output is variable during the different hours of the day, and the variation is accentuated by the reduction in the working hours. The compound compressed air engines, being very supple, adapt themselves much more readily to the variations of loading—precisely as occurs with compound steam locomotives—and during the hours of heavy outputs they haul very long trains, and with such a potentiality for speed that capable drivers profit by it so as to make the runs on the shortest time schedule.

Taking into consideration all factors, the conclusions arrived at are that at the present time the benzine motor merits the preference for the haulage operations of small collieries where from two to three locomotives at most suffice for the traction and where the first costs of installation must be kept low. Where there is a larger railway system to be dealt with, and costs of installation are of less importance, then compressed air is indicated.

By utilising the exhaust steam from stationary engines the compressed air for locomotives is produced very cheaply. By utilising this waste steam for compressing the air the cost per ton-kilometre is only about 6 centimes (about 1d. per ton-mile) in the "Deutscher Kaiser" Collieries, where there are a dozen compressed air locomotives in service during the two shifts per day.

27. Compressed-air Locomotives (3)

Field of work. This type of locomotive is adapted to all mines having compressed-air plant, and especially to gassy collieries or dry, timbered mines, in which electric or fuel-burning machines might be dangerous. ADVANTAGES: since the power is stored in the locomotive itself, it can operate wherever track is laid, returning at intervals to charging station; no trolley wires, with their attendant danger, are needed; no power consumed when the locomotive is idle; the exhaust tends to aid ventilation; power, greatly in excess of the average, is obtainable by temporarily using full tank press in the cylinders (3). But electric locos are generally more economical in running cost, if electric power is already installed for other service. For any given case, local conditions must be analyzed; data aiding in making choice are obtainable on request from H. K. Porter Co, Pittsburgh.

General construction. There are 1 or 2 storage tanks, which, with piping, etc, are carried on a frame mounted on 4 or 6 driving wheels. The cyls are usually simple, sometimes compound. The high-press air of the storage tanks passes into a small auxiliary tank, where it is reduced to proper working press, before going to the cyls.

Air pressure in storage tanks, 700 to 1 200 lb. Cyl press: simple engine, 125–150 lb; compound engine, 200–250 lb. Intermediate press for compound cyls, 50–60 lb. TANK CAPACITY, for hauls of 1 to 1.5 mile, 50–150 cu ft. For long hauls, it is better to increase press, rather than size of tanks.

Reheating (Art 16) restores heat lost in reducing press to that of the auxiliary tank; it is essential for compound cyls, the temp of exhaust from high-press cyl being far below freezing. Fig 63 shows the H. K. Porter Co's INTERHEATER for compound locomotives. Between the cyls is a shell filled with small tubes, through which the warm atmospheric air is drawn by the ejector action of the low-press exhaust. Nearly all the heat lost in the high-press cyl is thus restored, expanding the air about 36%. It is claimed that the use of the interheater effects a reduction of about 30% in

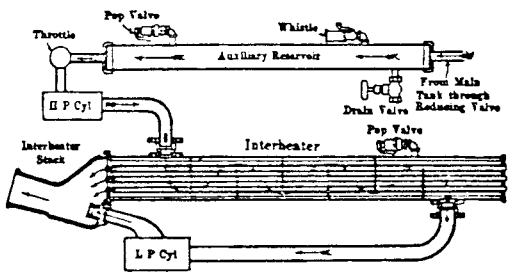


Fig 63. Diagram of Locomotive Cylinders and Interheater (H. K. Porter Co)

size of compressors and boilers, and in power costs, and of about 15% in first cost of installation; or an increase of about 30% in length of haul on 1 charge of air.

In gaseous mines a simple method of reheating is to inject into the auxiliary tank steam or hot water each time the locomotive is charged. In non-gaseous mines, a small oil or coke-burning furnace is used.

Table 69. Compressed-air Haulage Plants

Location	Locomotive wt, ton	Tanks: Capac, cu ft	Tanks: Air press, lb	Working press, lb	Cyls: Diam, in	Cyls: Stroke, in	Locos: Height, Length, Width, ft	Cars, wt: Empty, lb	Cars, wt: Load, lb	Cars in train	Max grade, %	Length round trip, ft	Charging time, sec
Buck Mt, Pa (*a*)	8	130	550	...	7	14	5.2×19× —	3400	7000	12	4.5	5100	...
Glen Lyon, Pa	8	130	550	160	7	14	.....	2800	7000	12–20	2.8	8000 / 4200	...
Grass Val, Cal	....	30	500	...	....		4.3×5×2.5	....	2000	5	....	....	...
Vivian, W Va (*b*)	5	....	500	125	5	10	4.5×0.5×5.8	8500		6	2.5	9000	20
P & R Coal & Ir (*c*)	....	....	600	180	....		.....	3300	5500	15–38	0.8	5200	60
" (*d*)	....	....	600	180	....		.....	.....	.....	4–10	5.5	3200	...
"	11	....	600	200	....		6.5×14×6.3	9000		32	1.7	....	...
Wilson Coll'y (*e*)	...	160	600	125	9	14	.....	5850		30	1.0	9000	85
Butte, Mont (*f*)	5	47	550	125	5	10	5×10.4×5	3450		6	0+	....	60
Anaconda, Mont	21 / 13	218 / 132	750	150	12×18 / 9.5×14		.....	....	....	....	....	1000 to 7000	...
Lead, S D (*g*)	5	....	....	....	....		5×10.5×3.3	....	....	....	....	....	...
Norway, Mich	7	....	700	140	7	12	5.2×12×4.2	1800	1800	20	....	1200 to 4000	45

Notes: (*a*) 1 loco delivered 150 cars in 10 hr, formerly requiring 10 mules. Aver cost per ton-mile: by air, gross, 1.875¢; net, 3.77 ¢; by mule, gross, 3.94¢; net, 7.92¢. (*b*) Cost of locomotive, $1 800. Max speed, 10 to 12 miles per hr. Capac of main storage tank, 47 cu ft at 535 lb press. Press in pipe line, 735 lb. (*c*) See "Cost of Plant" (3). Cost for 180 days per year: daily operating cost, $14.69; fixed charges @ 10% and cost of steam power, $9 per day; cost per day per car for 666 cars, 3.6¢ (previous cost by mule, 5.1¢ per day per car). (*d*) Locos are 4-cyl compound, 5 and 8 by 12 in. (*e*) Pipe-line press, 700 lb; air reheated. Cost per gross ton-mile, 1.25¢. (*f*) 2 round trips per charge on cold air; 3 on reheated air. (*g*) Locos have detachable rear end, to permit loading on to a 9-ft cage.

Tractive force of compressed-air locomotives may be found by $T = (D^2 \times L \times 0.98\,P) \div d$: where T = tractive force, lb; D = diam of piston, in; L = stroke, in; P = initial press, lb; $0.98\,P$ = effective cyl press; d = diam driving wheels, in (3). For compound cyls, the effective cyl press is taken as $0.85\,P$, P being actually the difference between the initial press in high- and low-press cyls; and it may be assumed that there are either 2 low-press or 2 high-press cyls, as the same power is generated in both.

Table 70. Compound Compressed-air Locomotives (H. K. Porter Co)

Class	Cylinders, in: Diam, h-p	Diam, l-p	Stroke	Rigid wheel base, ft, in	Length over bumpers, ft, in	Extreme width outside of gage, in	Height, ft, in	Main tank capac, cu ft	Weight in working order, lb	Tractive force, lb	Weight light-est rail per yd, lb	Radius sharpest curve, ft (*b*)
B-P-O	4.5	9	10	2 9	9 6 / 12 6	12½	(*a*)	20 / 60	7000 / 10000	1450	16	12
"	5.5	11	10	2 9	10 0 / 12 6	14½	(*a*)	30 / 75	10000 / 13000	2200	16	12
"	6	12	12	3 0 / 4 0	12 0 / 15 6	15	(*a*)	60 / 104	14000 / 17000	3000	20	15
"	7	14	14	4 0	12 0 / 18 6	16½	(*a*)	60 / 120	18000 / 22000	4400	30	20
P-B	4.5	9	10	2 9	9 6 / 12 6	12¼	8 0	20 / 60	5000 / 10000	1450	16	12
"	5.5	11	10	2 9	10 0 / 12 6	14¾	8 6	30 / 75	10000 / 13000	2200	16	12
"	6	12	12	3 0	12 0 / 15 6	15	"	60 / 104	14000 / 17000	3000	25	15
"	7	14	14	4 0	12 6 / 18 6	16½	9 0	60 / 120	18000 / 22000	4400	30	20
B-PP-O	7	14	14	4 0	14 0 / 20 0	16½	5 0 / 5 10	97 / 160 (*c*)	20000 / 27000	4400	30	16
"	8.5	12&12	14	4 6	16 0 / 20 0	16½	"	114 / 210 (*c*)	28000 / 36000	6400	40	18
"	9.5	14&14	14	4 6	18 0 / 21 0	18	"	160 / 275 (*c*)	32000 / 42000	8000	45	20
"	10	14&14	14	5 0	20 0 / 23 0	18	5 5 / 5 10	160 / 290 (*c*)	43000 / 46000	9000	50	25
B-PP	8.5	17	16	5 6	14 0 / 18 0	16½	10 0	114 / 210 (*d*)	28000 / 36000	6400	40	30
"	9.5	19	18	5 6	18 0 / 21 0	18	11 0	160 / 290 (*d*)	32000 / 42000	7500	45	30
"	11	22	18	5 9	19 0 / 22 0	25¼	12 0	260 / 375 (*d*)	55000 / 60000	10000	55	40
"	13	26	24	6 6	20 0 / 24 0	29¼	"	"	69000 / 73000	14500	65	50
"	15	30	24	6 6	22 0 / 26 0	33	"	"	95000 / 100000	19500	80	50
C-PP	7	14	14	5 6	14 0 / 20 0	16½	5 0 / 5 10	97 / 160 (*c*)	20000 / 27000	4400	25	30
"	8.5	12&12	14	5 6	16 0 / 20 0	16½	"	114 / 210 (*c*)	28000 / 36000	6400	30	30
"	9.5	14&14	14	5 6	18 0 / 21 0	18	"	160 / 275 (*c*)	32000 / 42000	8000	35	30
"	10	14&14	14	5 6	20 0 / 23 0	18	"	160 / 290 (*c*)	43000 / 46000	9200	40	50

(*a*) Depends on gage. (*b*) Radius advised, 25–50% greater. (*c*) 2 tanks. (*d*) 2 or 3 tanks. Main tanks are built for press of 700 or 1 200 lb; auxiliary tank press for all, 250 lb. Tenders accompany locos, if space is limited; useful for long hauls.

Charging compressors (Art 4) (3) are 3 or 4-stage, to divide the work of compressing to high tension between several cyls, for more efficient cooling. Also, with high press, care must be taken to keep valves and pistons tight, to use only a small quantity of high fire-test lubricating oil, and to insure that the cooling water runs freely and fills every jacket and intercooler whenever the compressor is running. It is well to provide the compressor with a fusible plug, which will melt in case of excessive temp, and warn the engineer to shut down and remove the cause of trouble.

Pipe lines and charging stations. With short hauls no pipe line is required, the locomotives being charged at the receiver. On long hauls, one or more charging stations are necessary.

The pipe line supplies added storage capacity. STORAGE CAPACITY and press of pipe line to produce a given press in locomotive tanks, are determined by $V\,(P - p) = v\,(p - p')$, in which, V = storage vol required, cu ft; v = vol of locomotive tanks, cu ft; P = pipe-line press, lb per sq in; p = desired press in locomotive tanks, lb per sq in; p' = residual press in locomotive tanks, just before charging, lb per sq in.

Pipe lines are usually 3 to 6-in, lap-welded, with calked sleeve joints. Charging station consists of a heavy tee, set in the main line, with a pipe containing one or more ball and socket joints, for connecting with locomotive tank (Fig 64). Charging time is from say 0.5 to 1.5 min (Table 69).

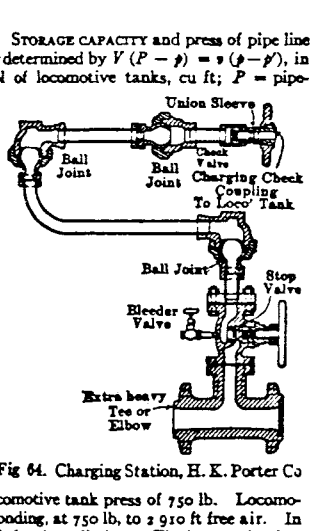


Fig 64. Charging Station, H. K. Porter Co

Operating data of compressed-air locomotives in collieries near Ems, Westphalia. The work is equivalent to about 262 ton-miles per 8-hr shift, haulage distance ranging from 2 295 to 4 590 ft. An 85-hp 3-stage compressor supplies 159 cu ft free air per min at 1 500 lb press. After compression, the air goes to a 35-cu ft receiver, and thence 897 ft down the shaft in a 1.5-in pipe. In the levels, 3 other 35-cu ft receivers are placed equidistant, for charging stations. In charging, reducing valves give a locomotive tank press of 750 lb. Locomotive storage tanks have 57 cu ft capacity, corresponding, at 750 lb, to 2 910 ft free air. In a small auxiliary tank the press is reduced to 150 lb for the cylinders. The locomotive has 4 19.5-in driving wheels; total wt 5.5 tons. Normal power is 8 to 12 hp; max, 24 hp; hauling capacity, 40 to 50 loaded cars, weighing 2 180 lb gross each, on an up-grade of 1 in 300 at a speed of 5.6 miles per hr. Actual running time per 8-hr shift for 2 locomotives was 313 min, 642 min being consumed in shunting and stoppages.

For costs and operating data of a number of plants, see Peele's Compressed Air Plant, 4th edn, 1925, Chap 26.

1920

BULLETIN

DE LA

SOCIÉTÉ DE L'INDUSTRIE MINÉRALE

ÉTUDE

SUR LES

LOCOMOTIVES A AIR COMPRIMÉ A TRIPLE EXPANSION

ET

L'UTILISATION DE LA VAPEUR D'ÉCHAPPEMENT

A LA

Production de l'air à haute pression

PAR

M. P.-E. LEROUX,

INGÉNIEUR DES ARTS ET MÉTIERS.

L'enlèvement rapide des produits de l'abatage s'impose de plus en plus à l'attention des exploitants de charbonnages, car il est intimement lié à la question de la main-d'œuvre du fond.

Etant donné sa rareté, l'élévation extraordinaire de son prix de revient et la limitation du temps de l'extraction, on se trouve dans l'absolue nécessité de recourir aux moyens mécaniques.

Les transports souterrains par locomotives qui commençaient à se répandre dans nos mines avant la guerre, deviendront bientôt la généralité.

Sans revenir sur les avantages et inconvénients des divers moyens de traction employés, nous pouvons dire que dans les mines de charbon la locomotive à air comprimé est la seule qui puisse être adoptée sans aucun danger et avec le plus d'économie.

Jusqu'à cette époque les locomotives n'avaient pas encore remplacé complètement l'emploi des chevaux au fond, nous pensons qu'il serait possible d'y arriver en installant à l'avant de la locomotive un petit treuil à moteur rotatif dont la poupée pourrait recevoir 200 à 300 mètres de câble en acier très souple de 6 à 8 mm. de diamètre, avec anneau à désaccrochage et arrêt automatique capable d'un effort de traction de 300 à 350 kilos et commandé de la cabine du mécanicien.

Dans les locomotives du fond, la partie motrice doit être facilement accessible, sa position entre les longerons ou intérieurement, oblige le mécanicien à sortir de sa cabine pour la moindre réparation et souvent nécessite des fosses de visite.

Etant donné le faible écartement des rails et l'encombrement réduit du gabarit des machines, les cylindres disposés soit à l'intérieur ou à l'extérieur des longerons, ont un diamètre relativement petit qui ne permet pas les expansions multiples par suite des diamètres qui sont nécessaires.

Notre nouvelle locomotive a été conçue pour obvier à ces inconvénients et réduire le plus possible la consommation en air et les frais d'entretien.

L'amovibilité du moteur, outre l'accessibilité de tous les organes, même en cours de route, permet un démontage des plus faciles, et son remontage au jour, en laissant au fond la partie châssis et réservoirs dont l'encombrement nécessitait à la remontée des manœuvres souvent laborieuses et très coûteuses.

L'application de la triple expansion réduit au minimum la consommation d'air. La récupération des freinages qui s'obtient par la marche du moteur en compresseur, permet d'utiliser le travail résistant, par production d'air comprimé et de chaleur accumulée dans les faisceaux tubulaires intercalés entre chaque expansion.

Après l'arrêt, le démarrage suivant se fait dans les conditions les plus avantageuses, puisqu'il existe une légère surpression au réservoir de travail et un excès de calories dans les réservoirs intermédiaires.

Notre locomotive démarre sous pleine charge, dans toutes les positions, car outre les avantages ci-dessus, nous avons prévu un appareil dépiqueur, permettant d'envoyer de l'air à haute pression dans les réservoirs intermédiaires.

Elle se compose (Fig. 1-2-3-4) d'un châssis en tôle d'acier, dont la partie arrière, formant le stand du conducteur, peut se démonter très rapidement pour permettre l'enlèvement du moteur.

Le châssis repose sur deux essieux moteurs droits, par l'intermédiaire de quatre ressorts à lames, disposés de façon à répartir uniformément les efforts de réaction par une absorption rationnelle des chocs.

Les roues sont calées sur les essieux ; elles sont constituées par un corps en fonte aciérée, avec bandages en acier dur laminé, sans soudure, d'une épaisseur largement suffisante pour supporter plusieurs tournages après usure en service.

Les roues sont reliées entre elles par des bielles d'accouplement.

La partie supérieure du châssis reçoit les réservoirs de charge qui peuvent être au nombre de cinq. Ils sont exécutés en acier doux d'une résistance de 35 à 40 kg. par mm² de section pour un allongement de 25 % ; ils communiquent entre eux par des raccords appropriés et l'ensemble est essayé à une pression de 225 kg. par cm², correspondant à une pression maximum de régime de 150 kg.

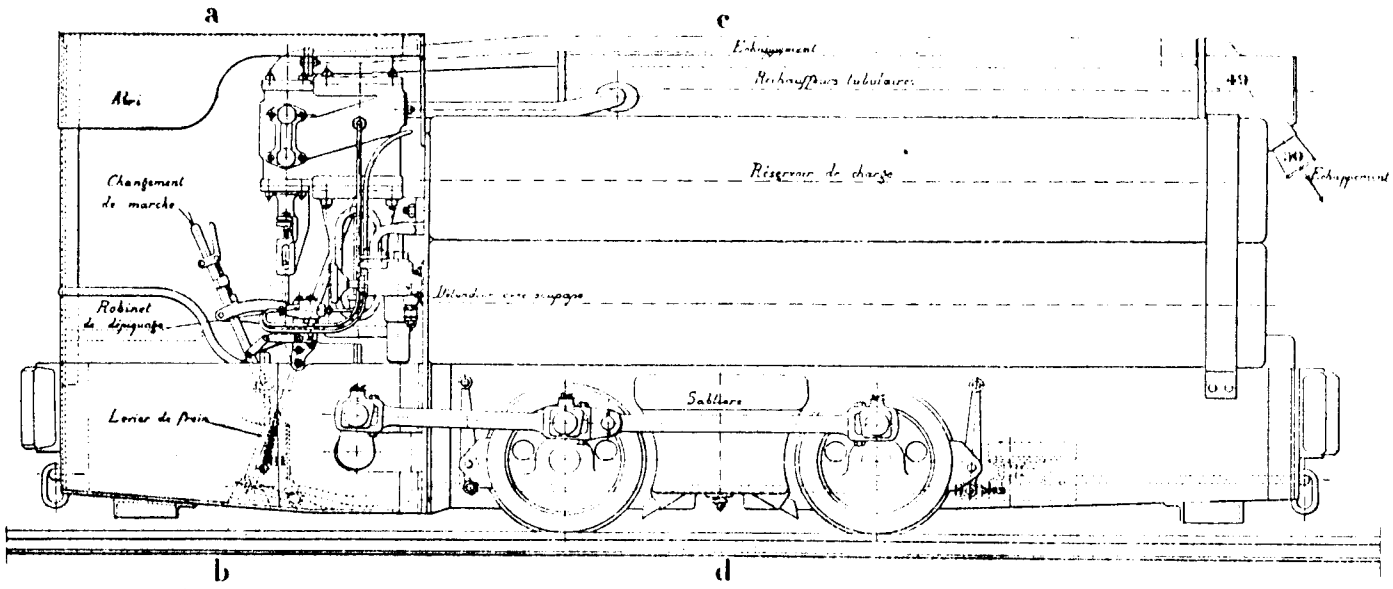
Les réservoirs sont solidement fixés sur le flasque arrière en tôle du châssis, ce flasque reçoit également le moteur.

Ce dernier est du type vertical et comporte deux cylindres parallèles (Fig. 5-6-7), le premier est à piston différentiel ; la partie (1) forme cylindre à haute pression ; celle (2) à moyenne pression. Le second (3) est le cylindre basse pression avec piston double effet.

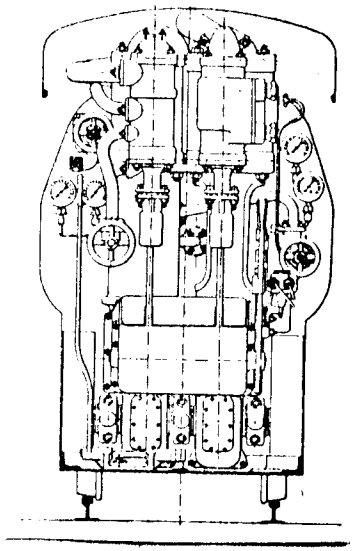
La longueur du piston haute pression assure un guidage parfait et permet de multiplier les segments de façon à obtenir une grande étanchéité tout en supprimant les inconvénients d'un presse-étoupes. Sur ce piston, est articulée en (5) la bielle motrice (5-6).

Le piston basse pression est du type « suédois » (Fig. 5).

Vue en élévation (fig. 1)



Coupe A B (fig. 2)



La glissière est cylindrique, la crosse 7 est prévue avec de larges patins, et la bielle motrice 7-8 est identique à la bielle 5-6, les coussinets de tête et de pied des bielles sont à rattrapage de jeu.

L'arbre moteur, en acier forgé traité, est supporté par trois paliers, ce qui permet d'obtenir le maximum de résistance avec une réduction sensible des dimensions des tourillons. Les deux manivelles transmettant le mouvement de l'arbre aux deux essieux sont venues de forge avec ledit arbre.

La distribution (brevetée S. G. D. G.) ne comporte pas d'excentrique, ce qui diminue notablement l'encombrement du moteur, tout en réduisant au minimum le nombre des organes.

Elle se compose (Fig. 5-6-7) d'une barre 9-10 articulée en 9 sur la bielle motrice et en 10 sur un coulisseau se déplaçant dans un guide cylindrique.

Sur cette barre en 11, est articulé le levier (11-12) dont l'extrémité (12) porte un coulisseau se déplaçant sur la coulisse (13-14). En 22 sur le levier 12/11 est articulée la bielle (22-23) de commande du tiroir de distribution.

Chaque tiroir comporte une distribution identique. Les deux coulisses sont fixées (Fig. 6) sur un arbre de relevage (15-16-17), les diverses positions de la coulisse, pivotant avec cet arbre permettent d'obtenir la variation de la détente ainsi que le renversement de la marche.

L'arbre est commandé par le levier de changement de marche (18/19) qui se meut sur un secteur denté (20-21) sur lequel il peut être fixé dans une position quelconque par un taquet d'arrêt muni d'un ressort de pression.

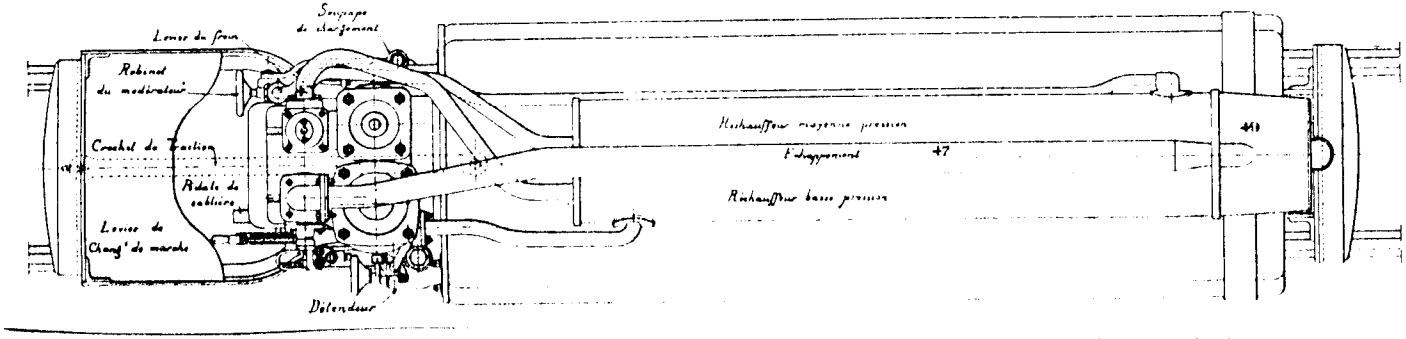
Cette disposition réalise par des organes peu coûteux et d'une très grande simplicité la marche avec variation de la détente et permet d'obtenir des phases identiques dans les deux sens de marche. La précision dans la distribution est comparable à celle des locomotives à vapeur perfectionnées.

Sur chaque boîte de distribution (Fig. 6 et 7) se trouvent montées des soupapes de refoulement (24 et 25) pour le cylindre basse pression, (26) pour le cylindre moyenne pression et 27 pour le cylindre haute pression.

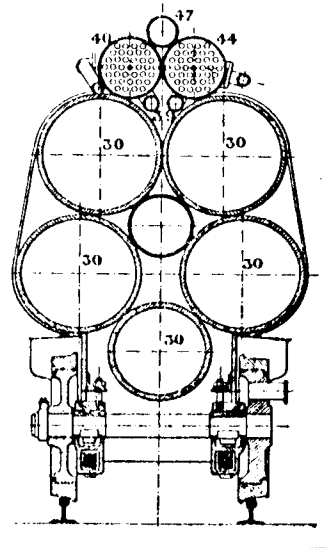
Ces soupapes en marche normale sont fermées automatiquement par la pression de l'air du réservoir alimentant le cylindre correspondant. Elles s'ouvrent dès que la pression de compression dans le cylindre dépasse la pression existant au réservoir (contremarche).

Le chargement de la locomotive (Fig. 6) se fait par une soupape (28) reliée à la conduite à haute pression par un flexible muni d'un raccord fileté à béquille (29).

Vue en plan (fig. 4)

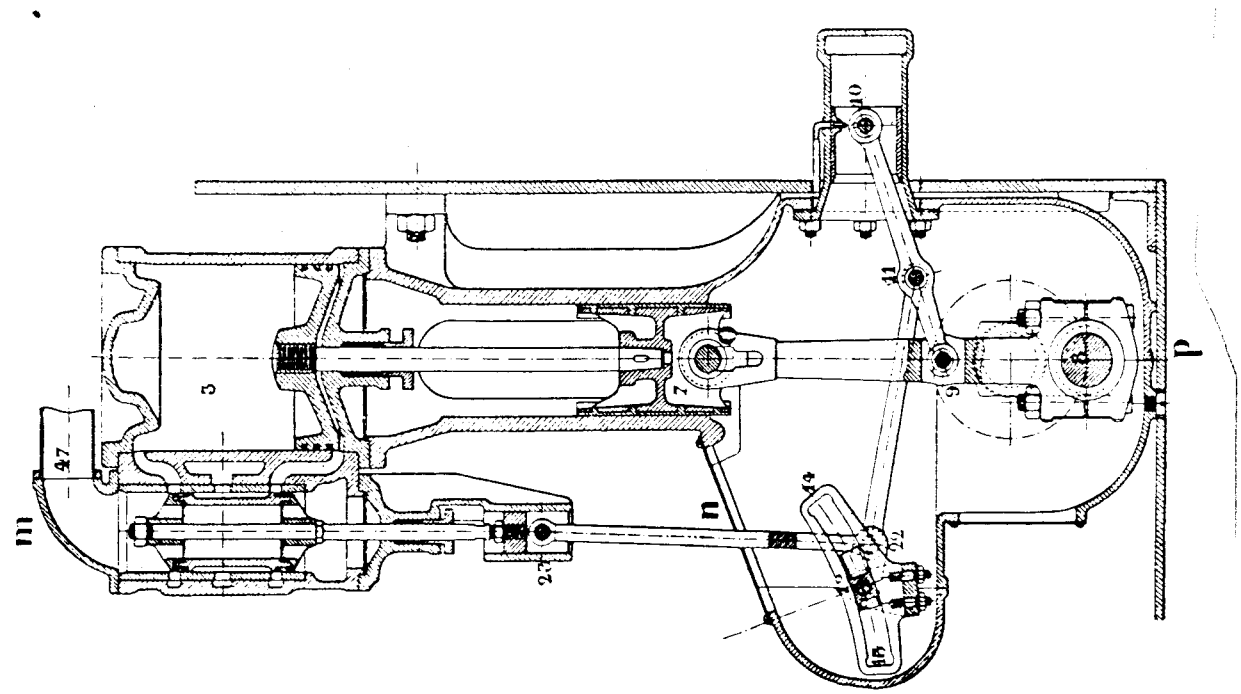


Coupe C D (fig. 3)

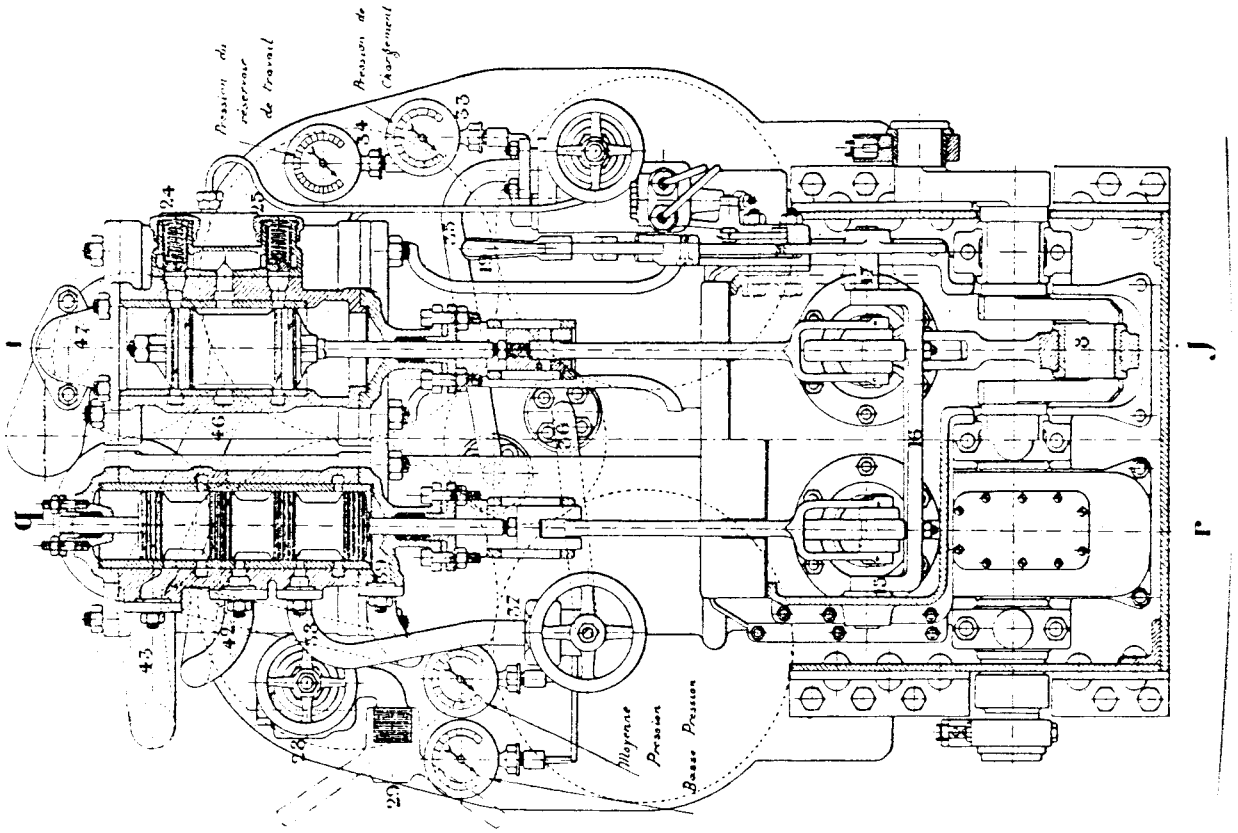


DÉTAIL DU MOTEUR A TRIPLE EXPANSION (1/5)

Coupe I J (fig. 5)

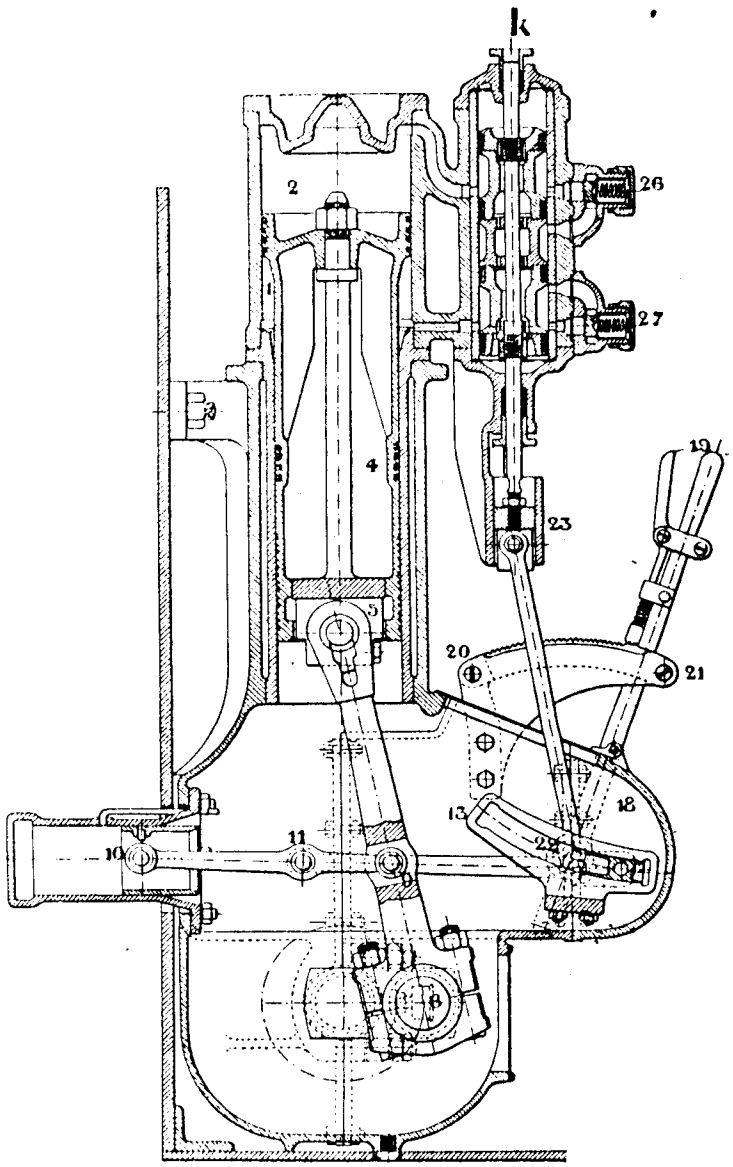


Coupe K L (fig. 6) Coupe M N O P



DÉTAIL DU MOTEUR
A TRIPLE EXPANSION (1/5)

Coupe Q R (fig. 7)



Cette soupape de chargement est munie d'un clapet de retenue qui empêche l'échappement de l'air comprimé dans l'atmosphère, si, par oubli, on dévissait le raccord avant sa fermeture.

En (32) se trouve fixé un détendeur muni d'une soupape de sûreté et d'un manomètre indicateur de pression (33).

Ce détendeur prend l'air comprimé à la pression des réservoirs et l'amène à celle du réservoir de travail avec laquelle il communique par le tuyau (35).

L'air moteur repris au réservoir de travail par le tuyau (36) passe par le robinet modérateur (37) pour se rendre à l'admission du cylindre haute pression en 38.

Après avoir travaillé sur la face annulaire du piston haute pression, l'air s'échappe en 39 et se rend (Fig. 3) au réservoir réchauffeur intermédiaire (40) d'où il est repris par un tuyau (41) et amené en (42) à l'admission moyenne pression ; puis s'échappe (Fig. 4 et 6) en (43) pour se rendre au second réservoir (Fig. 3) réchauffeur (44) et de là à l'admission (Fig. 6) du cylindre basse pression, en (46), et après détente s'échappe en (47).

L'échappement (47) se fait (Fig. 11-12-13-14) par une tuyère (48) dans une trompe (50), produisant un appel d'air dans une chambre en fonte (49) fixée en avant des faisceaux.

L'air extérieur aspiré traverse l'intérieur des tubes et réchauffe par contact l'air circulant entre les tubes.

Lorsque la locomotive est en marche, et que l'on veut provoquer son arrêt, on ramène le levier de changement de marche en sens inverse, ce qui provoque la marche du moteur en compresseur, l'air est aspiré par l'échappement du cylindre basse pression, puis comprimé suivant les différentes phases de l'admission, puis refoulé sans aucun refroidissement, dans les réservoirs tubulaires intermédiaires, puis dans celui de travail en réchauffant fortement chacun d'eux.

Le réservoir de travail et les deux réchauffeurs sont munis de soupapes de sûreté réglées pour fonctionnement à des pressions un peu supérieurd à la normale. Si, à la contre-

marche les pressions obtenues aux réservoirs dépassent celles pour lesquelles les soupapes sont réglées, celles-ci fonctionnent et il y a perte d'air ; mais la masse des réservoirs a emmagasiné une assez importante quantité de chaleur qui sera récupérée.

Par suite du travail résistant développé, la machine ne tarde pas à s'arrêter d'elle-même, et en cas de nécessité seulement, on peut faire agir parallèlement le frein à levier et à sabots, après la première manœuvre du levier de changement de marche, que l'on ramène au point milieu du secteur denté (20-21) après arrêt.

Nous récupérons ainsi en air comprimé et en chaleur emmagasinée dans la masse métallique des faisceaux tubulaires, une partie de l'énergie qui était autrefois totalement perdue avec le freinage sur les roues motrices, ce qui améliore sensiblement le rendement de la locomotive, comme le prouve d'ailleurs l'examen des diagrammes.

Pour mettre la locomotive en marche il suffit de déplacer le levier de changement de marche dans le sens voulu, jusqu'au dernier cran d'arrêt du secteur. Si la machine, à cause d'une position défavorable des manivelles, ne démarre pas, on continue à déplacer le levier, et, alors, on fait entrer en action l'appareil dépiqueur de démarrage.

Celui-ci (Fig. 8-9-10) se compose d'un corps en bronze (50) en communication par la tubulure (51) avec le réservoir de travail et par (52 et 53) avec les chambres d'admission des cylindres moteurs moyenne et basse pression.

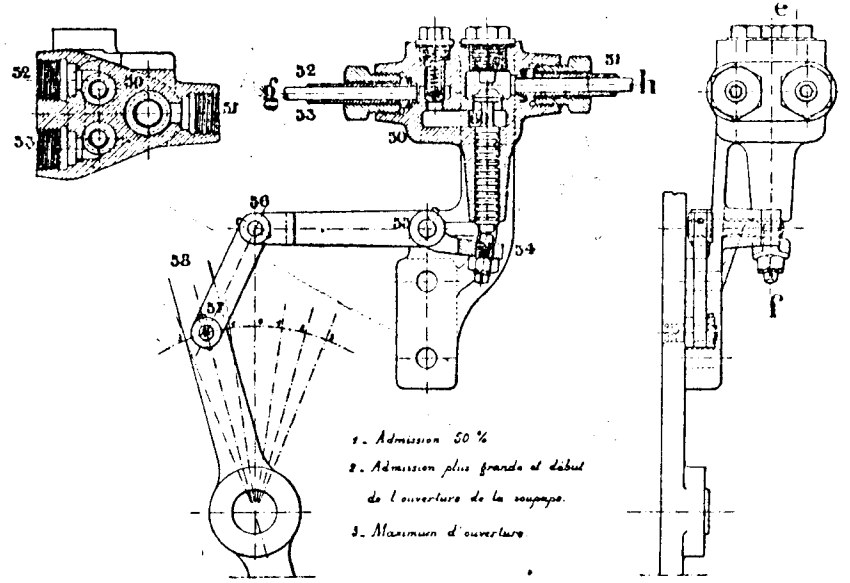
Les tubulures (52 et 53) sont munies de clapets de retenue et leur communication avec (51) est obtenue par le soulèvement du clapet (60). Ce clapet est commandé par le levier (54-56) oscillant autour d'un axe (55) fixé sur un support venu de fonderie avec la patte de fixation du corps du démarreur.

Ce levier est actionné par une biellette (56-57) articulée en (57) sur le levier de changement de marche (59-58).

Le démarreur n'entre en action que lorsque le levier de

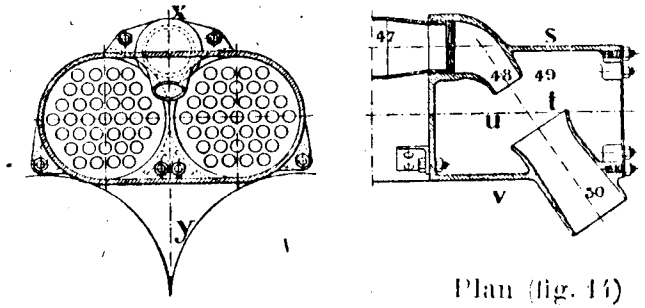
DÉPIQUEUR DE DÉMARRAGE (1/2)

Coupe G H (fig. 8) Coupe E F (fig. 9) Profil (fig. 10)

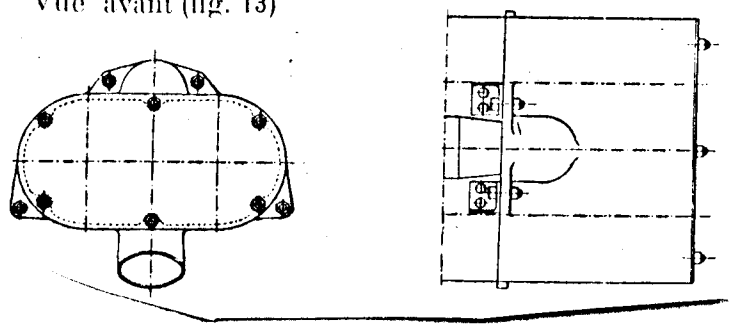


DÉTAILS DE LA TROMPE D'ÉCHAPPEMENT

Coupe S T U V (fig. 11) Coupe X Y (fig. 12)



Vue avant (fig. 13) Plan (fig. 14)



changement de marche se trouve aux points (2) du secteur, correspondant à l'admission normale la plus grande.

Le déplacement supplémentaire de (2) en (3) pour chaque sens de marche, correspond à une admission qui peut dépasser 90 %; en même temps la soupape (60) s'ouvre, en permettant l'alimentation directe des réchauffeurs.

Le couple moteur maximum est atteint et la locomotive démarre ; le déplacement supplémentaire du levier nécessite un supplément d'effort au mécanicien ; dès que la locomotive est démarrée celui-ci lâche instinctivement son levier qui, sollicité par les réactions de la distribution et par l'action du ressort à boudin (61) (Fig. 1) revient au premier cran d'arrêt qui donne l'admission maximum en marche normale.

En ramenant le levier plus près de la position moyenne, on donne à l'admission la valeur convenable.

L'ensemble du moteur et les différents organes sont bien accessibles sans aucun dérangement du mécanicien conducteur.

Les organes du mouvement et ceux de la distribution sont parfaitement à l'abri dans un carter étanche.

Etude d'une locomotive à triple expansion avec freinage pneumatique récupéré.

Les caractéristiques admises sont les suivantes :

Poids de la machine en ordre de marche..	6.500 kg.
Volume utile des réservoirs de la locomotive.	1.300 litres.
Pression de chargement des réservoirs...	150 kg. par cm².
Presssion résiduelle en fin de travail....	28-30 kg.
Diamètre du piston différentiel.....	160-195 mm.
Diamètre du piston BP.....	245 mm.
Course commune des pistons.....	210 mm.
Diamètre des roues motrices.....	0,500 mm.

Pression d'admission maximum au cylindre HP = 30 kg. par cm².

Nous avons étudié notre machine de façon à nous conformer autant que possible aux règles de la thermodynamie.

Dans la construction des machines thermiques ont doit obtenir l'ouverture et la fermeture rapide des obturateurs d'admission ou d'échappement du fluide moteur, surtout avec de l'air comprimé, dans ce but l'on a imaginé un grand nombre de systèmes de déclics très compliqués d'une usure rapide et d'un entretien fort coûteux. Notre distribution précédemment décrite nous permet d'obtenir très simplement l'avantage de la rapidité sans les inconvénients et la fragilité des dispositifs connus jusqu'à ce jour.

Nous ne reviendront pas sur la description déjà faite précédemment, nous allons seulement en étudier les différentes phases.

L'axe 9 (Fig. 20 et 21) décrit une courbe elliptique dont la longueur du grand axe est égale à la course du piston, le petit axe varie suivant la position du point sur la bielle.

Pour réduire la course des tiroirs et obtenir une distribution semblable dans les deux sens de marche AV et AR, nous avons (Fig. 5-6-7-20 et 21) prévu un levier 9-10 sur lequel est articulé le levier de commande du tiroir 11-12; dans lequel le point 11 décrit une courbe variable suivant sa position sur le levier 9-10, sa largeur augmente lorsque le point 11 se rapproche de 9 et diminue en se rapprochant du point 10.

Par suite des déplacements successifs du point 12 dans le secteur formant glissière 13-14, le point 22 décrit une courbe dont l'inclinaison varie suivant la position du secteur glissière 13-14, ce qui permet d'obtenir le changement de marche suivant qu'on place ce dernier dans un sens ou dans l'autre.

Suivant qu'on éloigne le point 9 des points 6 ou 8 et qu'on augmente les distances 12-22 et 10-11 par rapport à 11-22 et 9-11 plus la course du tiroir augmente, en variant ces différentes positions et longueurs on modifie les phases de la distribution.

Trace de la distribution (Fig. 20 et 21).

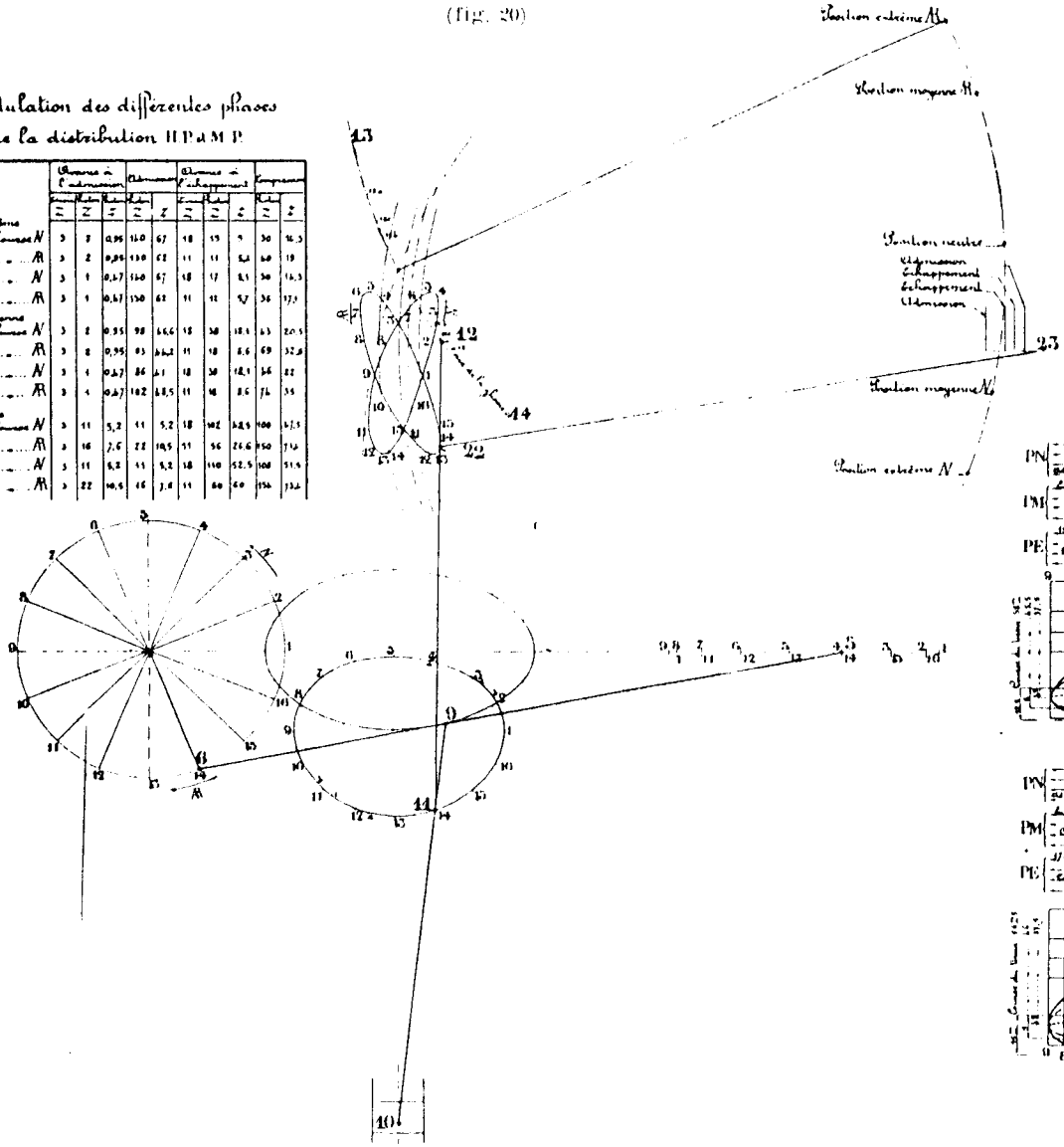
Nous nous imposons une admission de 60 à 65 % de la course du piston.

ÉPURES DE DISTRIBUTION ET ÉTUDE DES EFFORTS DEVELOPPÉS

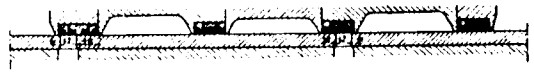
(fig. 20)

Récapitulation des différentes phases de la distribution H P et M P

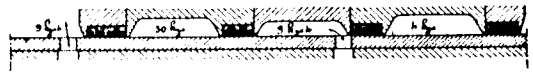
		Avance à l'admission		Admission		Avance à l'échappement		Échappement	
		⌀	⌀	⌀	⌀	⌀	⌀	⌀	⌀
Fonction extrême									
Manche N	Carnet N	3	2	0,95	110	67	18	15	9	30	16,5
	" R	3	2	0,95	110	62	11	11	8,5	30	19
Manche R	" N	3	1	0,67	110	67	18	17	8,1	30	16,5
	" R	3	1	0,67	110	62	11	12	9,7	36	17,5
Fonction moyenne											
Manche N	Carnet N	3	2	0,95	98	66,6	18	30	18,1	63	20,5
	" R	3	2	0,95	93	66,2	11	18	8,6	69	32,8
Manche R	" N	3	1	0,67	86	61	18	30	18,1	56	22
	" R	3	1	0,67	102	68,5	11	18	8,6	71	35
Fonction neutre											
Manche N	Carnet N	3	11	5,2	11	5,2	18	102	58,5	100	41,5
	" R	3	16	7,6	22	10,5	11	56	26,6	150	71,4
Manche R	" N	3	11	5,2	11	5,2	18	110	52,5	108	51,6
	" R	3	22	10,5	16	7,6	11	60	29	156	73,4



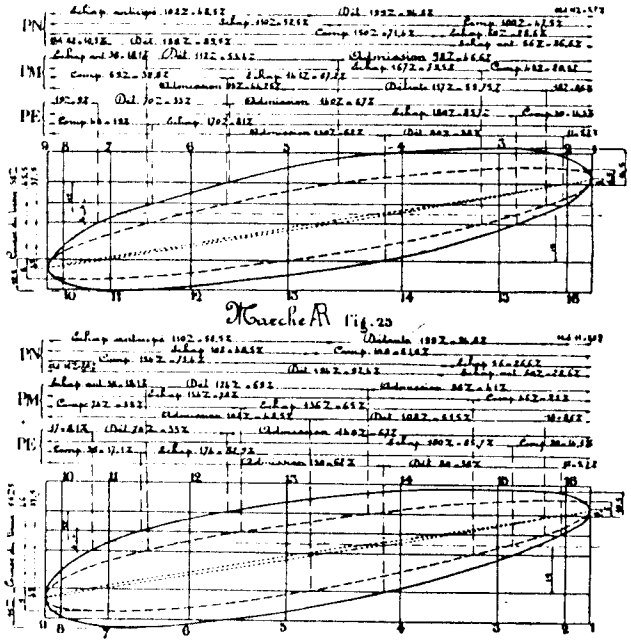
Position du tiroir montrant les recouvrements (fig. 22)



Position du tiroir correspondant au point 14 et à l'admission *N* (fig. 23)



Courbes représentatives des déplacements des tiroirs H P et M P. Marche *N* (fig. 24)
Echelle 1/3.

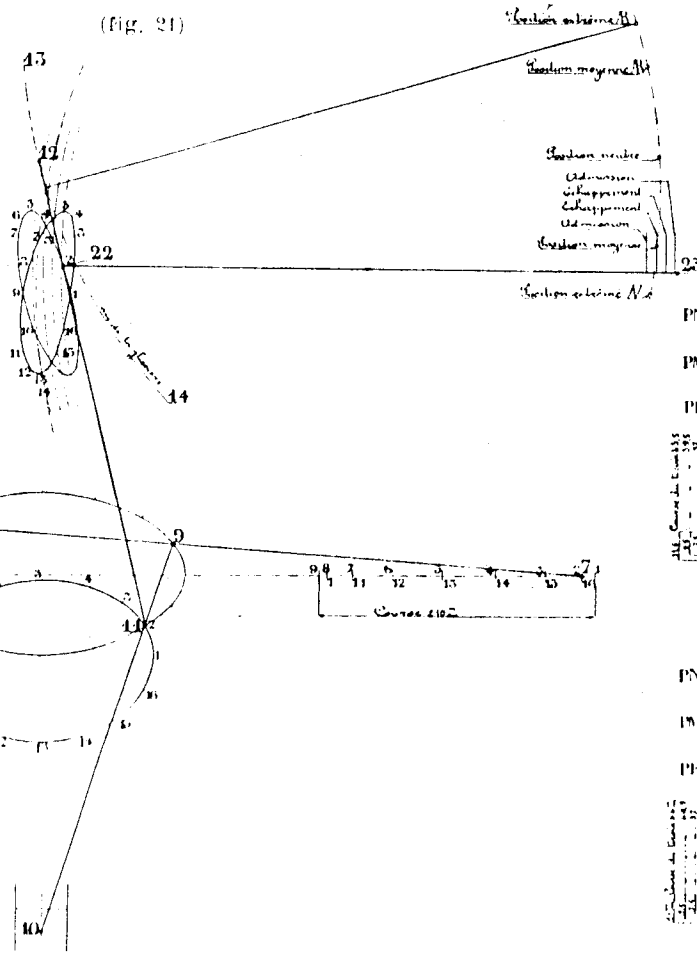


Marche A fig. 25

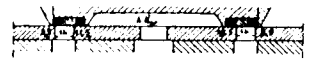
Récapitulation des différentes phases de la distribution B P

		Avances à l'admission			Admission		Avances à l'échappement			Compression		
Tiroir extérieur												
Manivelle N	Course N	6	10	4,75	110	92,5	16	21	15,2	61	29
	Course R	8	10	3,75	110	92,5	15	21	14,2	66	31
Manivelle R	Course N	8	14	6,7	110	92,5	15	20	14,3	66	30,5
	Course R	7	6	2,85	110	92,5	15	26	13	60	28,5
Tiroir intérieur												
Manivelle N	Course N	6	16	7,5	87	63,5	18	55	26,2	76	36,2
	Course R	8	18	8,5	86	63	15	54	25	86	41
Manivelle R	Course N	8	14	6,7	86	63	15	53	23	80	38
	Course R	7	14	6,7	90	63	15	56	22	85	40,5
Tiroir moyen												
Manivelle N	Course N	7	36	17,2	35	17,2	15	93	34,2	125	58,5
	Course R	7	38	17,8	38	18,1	15	89	38	116	55
Manivelle R	Course N	7	36	17,2	36	17,2	15	53	24,5	117	55,5
	Course R	7	38	18,1	43	21,8	15	76	35	130	62

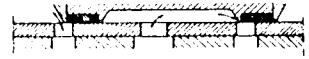
(Fig. 21)



Position du tiroir montrant les recouvrements (fig. 26)

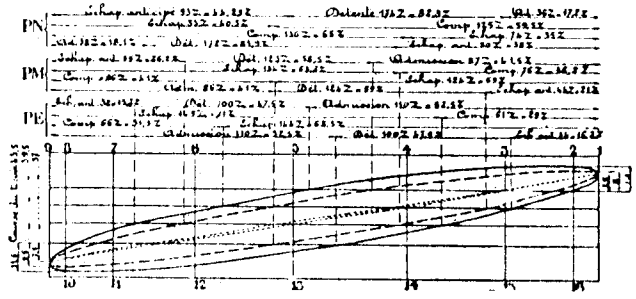


Position du tiroir correspondant au point 2 et à l'échappement AR (fig. 27)

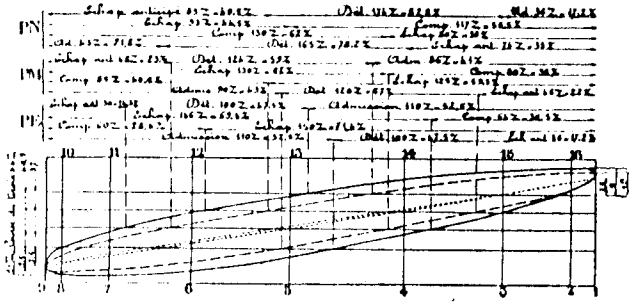


Courbes représentatives des déplacements du tiroir B P

Marche *N* (fig. 28)



Marche AR (fig. 29)



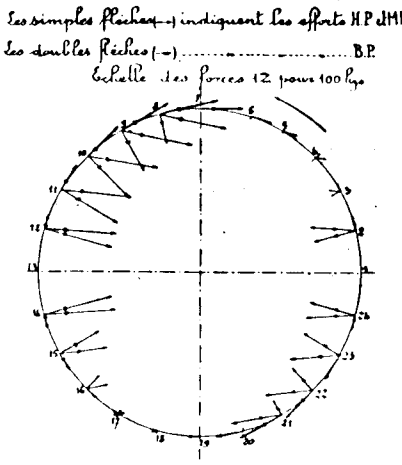
Nous traçons notre tiroir et prenons le point 9 aussi *près* que possible de la manivelle afin de réduire l'épaisseur ou largeur de la courbe décrite par le point 22, et par suite de réduire la course du tiroir.

Le degré de détente admis nous imposant des ouvertures de lumières relativement faibles, nous prenons les rapports 11-22 à 12-22 et 9-11 à 10-11 aussi grands que possible.

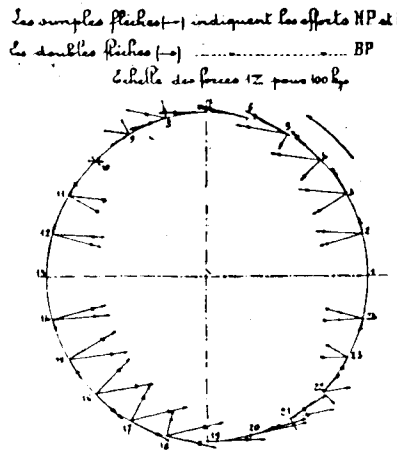
Des différentes positions du point 23 correspondant aux courses du tiroir donnant les degrés d'admission et d'échappement prévus, nous traçons des arcs de cercle en prenant des rayons convenables pour qu'ils se coupent en un point placé sur l'axe vertical de la courbe décrite par le point 11.

Ce point où ces deux arcs de cercle se coupent constitue le centre des courbes décrites par le point 22 dans les deux sens de marche AV et AR.

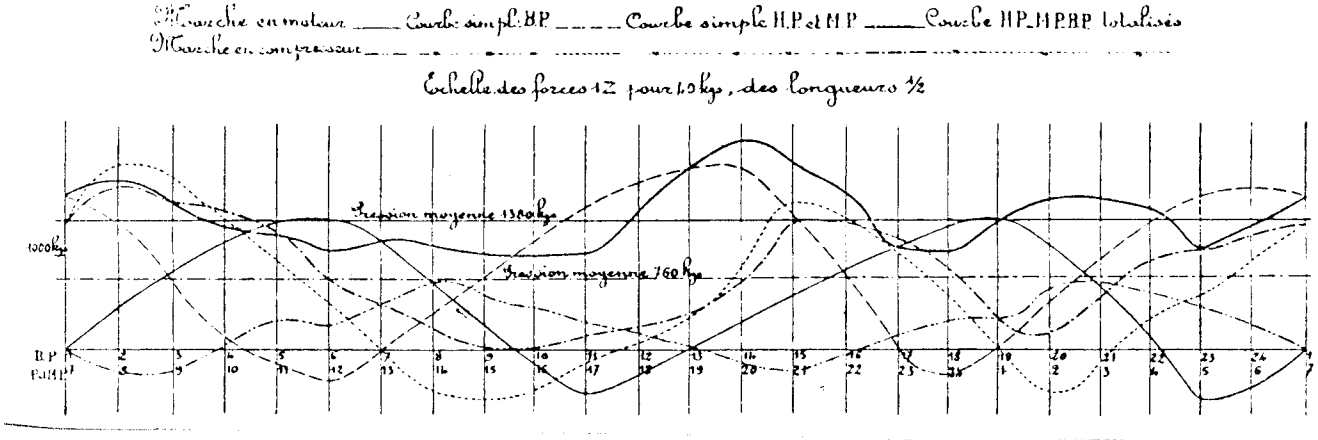
Décomposition des efforts moteurs (fig. 31)



Décomposition des efforts de freinage (fig. 32)



Courbes des efforts tangentiels admission de 62 % (fig. 30)


Marche en moteur ____ Courbe simple BP ____ Courbe simple HP et MP ____ Courbe HP MP BP totalisées
Marche en compresseur
Echelle des forces 12 pour 100 kgs, des longueurs ½
Pression moyenne 1380 kgs
1000 kgs
Pression moyenne 760 kgs
BP
HP MP

Des points correspondant dans le sens de marche AV et AR aux admissions *a*, échappement *b*, compression *c*, prévus pour l'admission imposée nous plaçons une bande de papier représentant la bielle 11-22-12 dont le point 22 doit se trouver sur les arcs de cercle représentatifs de l'échappement et de l'admission AV et AR, nous faisons glisser cette bande de papier en maintenant le point 11 sur la courbe qu'il décrit dans son mouvement correspondant à la rotation de la manivelle motrice, et le point 22 comme il est dit sur les courbes AV et AR, ce qui nous permet d'obtenir les points 12 *a*, 12 *b* et 12 *c* représentant respectivement l'admission, l'échappement et la compression relativement à l'admission imposée.

Par tâtonnements successifs nous nous efforçons de faire passer l'axe du secteur glissière 13-14 de changement de marche par les points 12 *a*, 12 *b*, 12 *c*. Nous obtenons ainsi les admissions moyennes de 62 % au cylindre HP, 67 % au cylindre MP et 52,5 % au cylindre BP. Nous avons en outre dirigé nos tâtonnements de façon à obtenir des efforts sensiblement égaux.

Etude des phases de la distribution.

Dans la prévision de nos volumes de cylindrées, nous nous imposons comme pression moyenne dans les réchauffeurs 9 kg. par cm² entre la première et la deuxième expansion, et 4 kg. par cm² entre la deuxième et la troisième expansion.

Pour le tracé des diagrammes (Fig. 33) pour la marche en moteur (position extrême) nous prenons pour les espaces morts des volumes approximatifs de 01.250 pour H P, 01.350 pour M P et 01.600 pour B P.

Volume de chacun des réchauffeurs, environ 42 litres.

$$\text{Volume d'une cylindrée BP } \frac{3.1416 \times 2,42}{4} \times 2,1 = 91.500.$$

Comme une cylindrée M P doit fournir l'air nécessaire à deux cylindrées BP, soit un volume de $91.5 \times 2 = 19$ litres représentés sur nos diagrammes (Fig. 33 et 34) par :

$$\frac{210 \text{ mm.}}{19} = 11 \text{ mm. } 05 \text{ par litre.}$$

$$\text{Volume d'une cylindrée M P } \frac{3.1416 \times 1.95}{4} \times 2,1 = 61.27.$$

Représentés sur les diagrammes par : $6,27 \times 11,05 = 69$ mm.

Volume d'une cylindrée H P :

$$\frac{3.1416 \times 1,95^2}{4} - \frac{3.1416 \times 1,6^2}{4} \times 2,1 = 21.05.$$

Représentés sur les diagrammes par :

$$11,05 \times 2,05 = 22 \text{ mm. } 5.$$

Avec une admission de 62 % au cylindre H P, soit une introduction de 130 mm. (Fig. 33), le volume admis sera de $0,976 \times 1,3 = 11.270$.

En y ajoutant le volume de l'espace mort nous aurons :

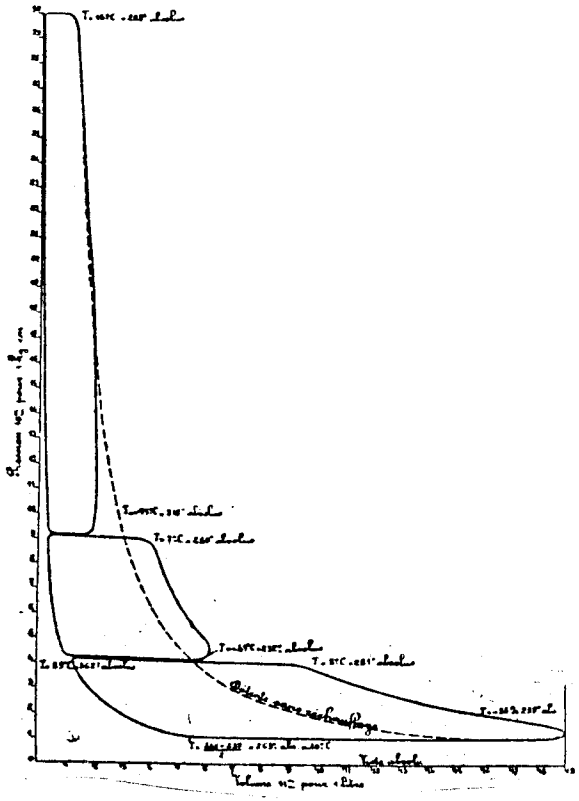
$$11.270 + 01.250 = 11.520.$$

Pour tenir compte des étranglements et résistances possibles nous prendrons une pression d'admission de 28 kg. 5 au lieu de 30 kg. pression au réservoir de travail.

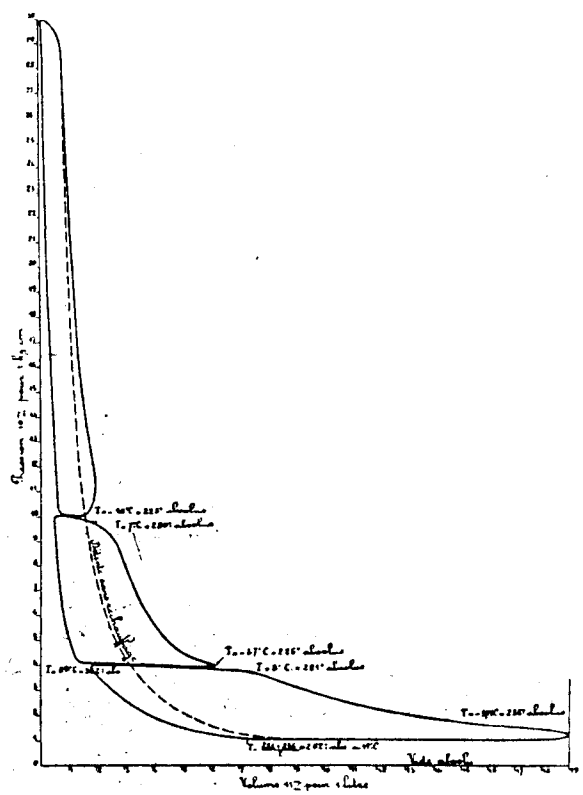
Le volume contenu dans le cylindre au moment de l'ouverture de l'échappement sera de :

$$0,976 \times 1,99 + 01.250. = 21.192$$

Diagrammes moteurs, admission H P 62 % (fig. 33)



Diagrammes moteurs, admission H P 44 % (fig. 34)



La pression sera de :

$$28 \text{ kg, } 5 : \frac{2.192}{1.520}^{1,3} = 17 \text{ kg, } 8.$$

Dans cette équation 1,3 représentant l'exposant correspondant à la détente polytropique que nous avons adopté (voir Fig. 37).

Volume au début de la compression H P.

$$0,976 \times 0,36 + 0,250 = 01.60.$$

Volume à la pression initiale de 30 kg. par cm².

$$01.60 : \frac{30}{9,4} \frac{1}{1,3} = 01.246.$$

D'après l'examen des diagrammes et ce qui précède, nous voyons que le volume d'air à la pression initiale de 30 kg. par cm² fourni par la compression est à peine suffisante pour

remplir l'espace mort.

Volume de l'air détendu et fourni au réchauffeur situé entre la première et la deuxième expansions au MP, par tour de manivelle :

$$\frac{28\,kg,5}{9\,kg.}\ \frac{1}{1,3} \times 1.270 = 3\,l.060 \text{ à } 9 \text{ kg. par cm}^2.$$

Nous adoptons une température moyenne celle de l'ambiance de 15 degrés centigrades soit :

$$15° + 275° = 288 \text{ degrés absolus.}$$

La température de l'air à l'entrée du réchauffeur MP sera de :

$$288° : \frac{30\,kg.}{9\,kg.}\ \frac{1,3 - 1}{1,3} = 218 \text{ degrés absolus}$$

Soit 55 degrés centigrades.

Volume d'air introduit dans le réchauffeur MP par heure à la vitesse de 15 kilomètres à l'heure.

$$3\,l.06 \times 160 \text{ t. m.} \times 60 = 29.376 \text{ litres.}$$

Temps employé par une cylindrée pour circuler dans le réchauffeur MP :

$$1 : \frac{29.376}{42} = 0\,k\,00143$$

Nombre de calories transmises par le faisceau tubulaire (d'après le formulaire) :

$$Q = l \times \pi \times Z \times \frac{t1 - t2}{\frac{1}{\alpha \times di} + \frac{1}{\alpha \times da} + \frac{1}{2\lambda} \log \frac{di}{da}}$$

Formule dans laquelle :

l = longueur utile des tubes du faisceau tubulaire du réchauffeur.

$t1$ = température de l'air ambiant.

$t2$ = température de l'air à l'intérieur du réchauffeur.

α = coefficient de transmission de chaleur de l'air égal à 5 d'après le formulaire.

di = diamètre intérieur des tubes de 20 mm.

da = diamètre extérieur des tubes 23 mm.

λ = coefficient de conductibilité des parois, 35 à 45 pour l'acier doux et 55 à 110 pour le laiton nous prendrons 40 et 55.

n = nombre de tubes, pour notre cas 37.

En remplaçant les lettres par leur valeur, nous obtenons :

$$Q = 2 \times 3,1416 \times 0,00143 \frac{288 - 218}{\frac{1}{5 \times 0,020} + \frac{1}{5 \times 0,023} + \frac{1}{2 \times 55} \log \frac{0,023}{0,020}}\ 37 = 1,25$$

Pour le tube formant l'enveloppe extérieure du réchauffeur, nous aurons :

$$Q = 2 \times 3,1416 \times 0,00143 \frac{288 - 218}{\frac{1}{5 \times 0,212} + \frac{1}{5 \times 0,220} + \frac{1}{2 \times 40} \log \frac{0,220}{0,212}} = 0,34$$

Soit un total de $1,25 + 0,34 = 1,59$.

Nous avons également $Q = k\ S\ z\ (t1 - t2)$.

Formule dans laquelle :

z — le temps en heures.

k = coefficient variant avec la vitesse que nous prenons égal à 2,8 d'après le formulaire.

S = surface du réchauffeur en contact avec l'air ambiant, pour notre cas égal à 6 m² 23.

Nous tirons :

$$t1 = \frac{Q}{k\ z\ S} + t2.$$

En remplaçant les lettres par leur valeur, nous avons :

$$t1 = \frac{1,59}{2,8 \times 6,23 \times 0,00143} + 218 = 280°.$$

D'après ce qui précède nous avons vu que la température de l'air ambiant étant de 15°, correspondant à 288 degrés absolus, et que la température de l'air à la sortie du réchauffeur MP est de 280°, il y a une différence de 8° avec la température de l'air à la pression d'admission initiale de 30 kg. par cm².

Pour obtenir le volume d'air moteur admis au cylindre MP nous admettons que cet air se détend d'après cette différence de température de 8°.

D'après le formulaire nous avons :

$$\frac{P1}{P2}^{\frac{n-1}{n}} = \frac{t1}{t2}$$

Formule dans laquelle :

P1 = la pression d'admission au cylindre ch.

P2 = la pression d'admission au cylindre MP.

$t1$ = la température de l'air admis au cylindre HP.

$t2$ = la température de l'air admis au cylindre MP.

n = exposant pour détente polytropique.

De cette formule nous tirons :

$$\log \frac{P1}{P2}^{\frac{n-1}{n}} = \log \frac{t}{t2} \text{ et } \frac{n-1}{n} = \log \frac{t1}{t2} : \log \frac{P1}{P2}$$

En remplaçant les lettres par leur valeur on obtient :

$$\frac{n-1}{n} = \log \frac{288}{280} : \log \frac{30}{9} \quad \frac{0{,}013}{0{,}532} = 0{,}025$$

Et l'on tire :

$$N = 1{,}0255$$

Nous allons déterminer le volume d'air à kg. par cm² disponible par tour de manivelle pour le cylindre MP, nous avons :

$$1.210 \frac{30 \text{ kg.}}{9 \text{ kg.}}^{1{,}0255} = 3\,1.\,900$$

Pour tenir compte des pertes possibles, nous prendrons 3 l. 850.

Au début de la compression le volume sera de :

$$\frac{2{,}98}{\frac{1}{1{,}3}} \times 0{,}3 + 0{,}350 = 1\,1.\,245$$

Volume de la pression de 9 kg par cm².

$$1{,}245 : \frac{9}{4}\,\frac{1}{1{,}3} = 0\,1.\,670$$

Le volume d'admission au cylindre MP sera, d'après ce qui précède de :

$$3\,1.\,850 + 0{,}670 - 0\,1.\,350 = 4\,1.\,17$$

Représentant une partie de la course égale à :

$$\frac{41.17}{2{,}98} = 140 \text{ mm.}$$

Le volume contenu dans le cylindre MP au moment de l'échappement sera de :

$$2\,1.\,98 \times 1{,}91 + 0{,}350 = 6\,1.\,05$$

A une pression d'échappement de :

$$9 \text{ kg } \frac{6{,}05}{4{,}17 + 0{,}35}\,1.3 = 6 \text{ kg } 2 \text{ par cm}^2.$$

Le volume de l'air détendu qui s'échappera dans le réchauffeur situé entre la deuxième et la troisième expansion ou basse pression (BP) sera de :

$$\frac{9}{4}\,\frac{1}{1{,}3} \times 3\,1.\,850 = 7\,1.\,15 \text{ à } 4 \text{ kg par cm}^2$$

La température de l'air à l'entrée du réchauffeur BP sera de :

$$280 : \frac{9}{4}\,\frac{1{,}3-1}{1} = 232 \text{ degrés absolus, soit } 41 \text{ degrés centigrades.}$$

Le volume d'air horaire introduit dans le réchauffeur BP, la locomotive marchant à la vitesse de 15 kilom. à l'heure sera de :

$$7\,1.\,15 \times 160 \text{ t. m.} \times 60 = 68.800 \text{ litres.}$$

Temps que met une cylindrée pour traverser le faisceau tubulaire du réchauffeur BP.

$$1 : \frac{68.800}{42} = 0 \text{ h. } 00061$$

Nombre de calories transmises à l'air par le faisceau tubulaire du réchauffeur BP :

$$2 \times 3{,}1416 \times 0 \text{h.} 0061 \; \frac{288 - 252}{\frac{1}{5 \times 0{,}02} + \frac{1}{5 \times 0{,}023} + \frac{1}{2 \times 55} \log \frac{0{,}023}{0{,}02}} \times 57 = 0{,}422 \text{ calories}$$

Pour le tube extérieur formant l'enveloppe du réchauffeur BP, nous avons :

$$2 \times 3{,}1416 \times 0\text{h}.00061 \frac{288 - 252}{\frac{1}{5 \times 0{,}212} + \frac{1}{5 \times 0{,}22} + \frac{1}{2 \times 40} \log \frac{0{,}22}{0{,}212}} = 0{,}115 \text{ calories}$$

Soit un total de 0,422 + 0,115 — 0,537 calories.

D'où l'on a : $t1 = \frac{0{,}557}{2{,}8 \times 6{,}23 \times 0{,}00061} + 252 = 281$ degrés absolus

Volume d'air à 4 kg par cm² disponible au cylindre BP par tour de manivelle :

$$31.850 \frac{9}{3{,}9} 1{,}03 = 81.65$$

Pour tenir compte des pertes possibles nous prendrons 81. 60 par tour de manivelle.

Volume dans le cylindre BP au début de la compression :

$$4{,}52 \times 0{,}63 + 0{,}6 = 31.45$$

Volume à la pression de 4 kg. par cm²,

$$31.45 : \frac{4}{1{,}1} = 11.280$$

Le volume d'admission à chaque introduction par course du piston BP sera :

$$\frac{81.60}{2} \times 1{,}280 \times 0{,}6 = 41.98$$

Correspondant à une course du piston de :

$$\frac{41.98}{4{,}52} = 110 \text{ mm.}$$

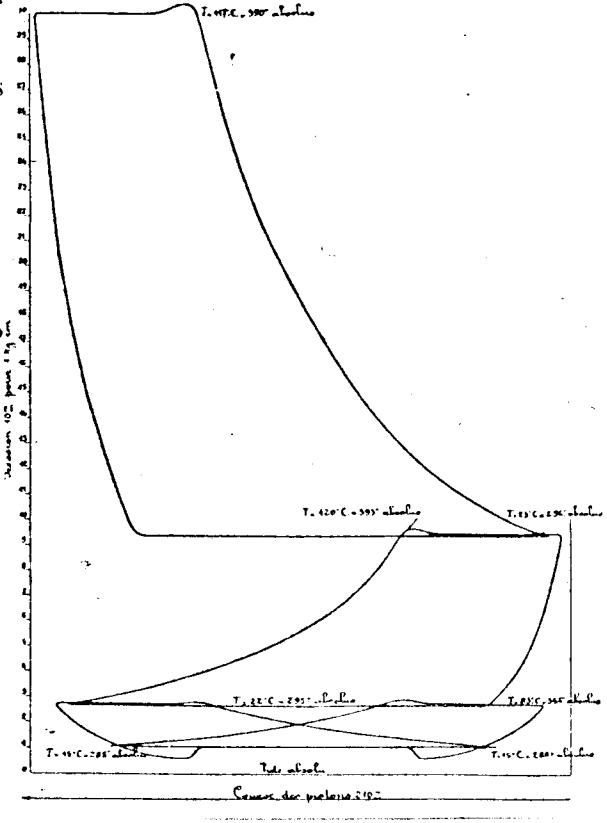
Volume contenu dans le cylindre BP au moment de l'ouverture de l'échappement :

$$4{,}52 \times 1{,}77 + 0{,}6 = 81.600$$

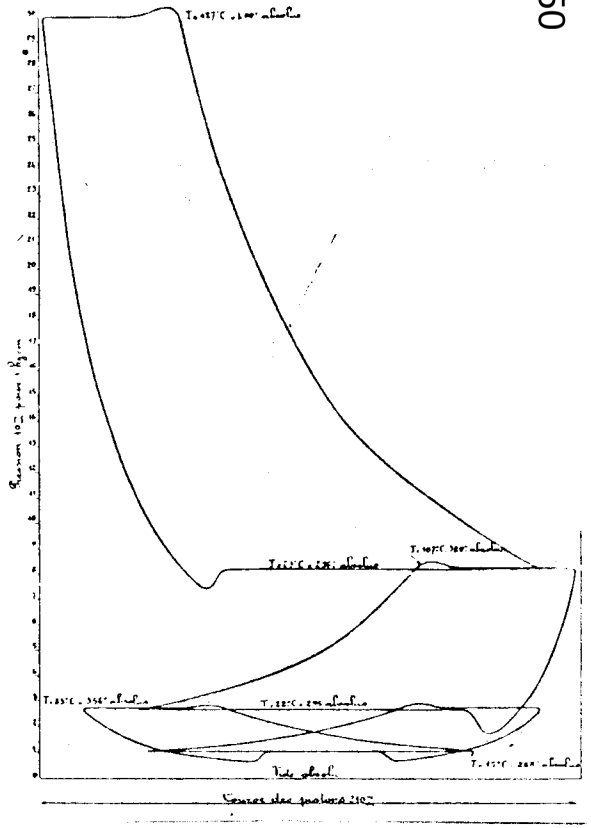
A une pression de :

$$3{,}9 : \frac{8.6}{4{,}98 \times 0{,}6}^{1{,}3} = 2 \text{ kg. } 23 \text{ par cm}^2.$$

Diagrammes de freinage, cran de 62 % (fig. 35)



Diagrammes de freinage, cran de 44 % (fig. 36)



A une température de :

$$281 : \frac{3{,}9}{2{,}23}^{\frac{1\text{-}3\text{-}1}{1{,}3}} = 239 \text{ degrés absolus.}$$

En opérant comme précédemment pour les autres degrés d'admission et la marche en compression, nous avons obtenu les données nécessaires pour nous permettre le tracé (Fig. 34, 35, 36, 37, 38 et 39) des différents diagrammes.

Pour tracer les courbes des efforts tangentiels nous avons divisé la circonférence décrite par la manivelle en 24 parties égales et déterminé les efforts correspondants à chaque point correspondant (Fig. 31, 32, 38 et 39) de la course du piston divisée également en 24 parties ; nous les avons décomposées en efforts tangentiels et en efforts sur l'arbre moteur.

Sur une horizontale d'une longueur représentant le développement de la circonférence décrite par la manivelle motrice (Fig. 30 et 40), nous portons les divisions précédentes et aux différents points obtenus sur les perpendiculaires qui y sont élevées, à une échelle convenable les différents efforts ce qui nous permet de tracer les courbes représentatives des efforts des pistons HP, MP et BP.

Nous obtenons ainsi un effort moyen de 1.380 kg. pour la marche en moteur avec une admission de 62 % au cylindre HP.

710 kg. pour la marche en compression avec le levier de changement de marche au cran d'admission de 62 %.

900 kg. pour la marche en moteur avec une admission de 44 % au cylindre HP.

648 kg. pour la marche en compression, le levier de changement de marche au cran d'admission de 44 %.

Diagramme H P, position neutre

(fig. 37)

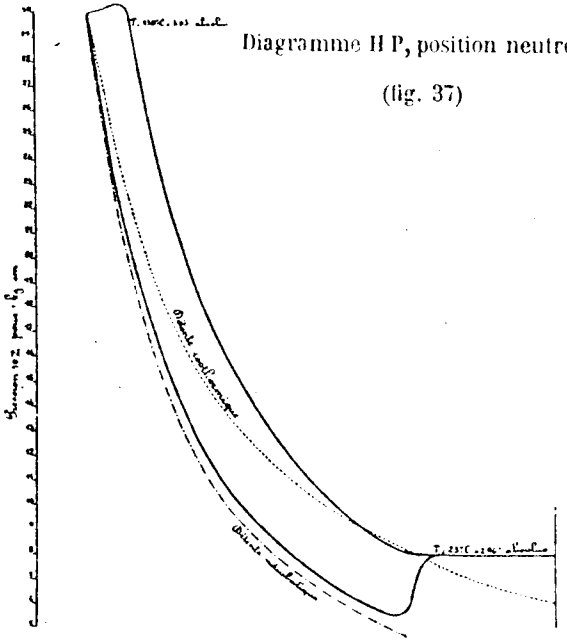


Diagramme M P, position neutre (fig. 38)

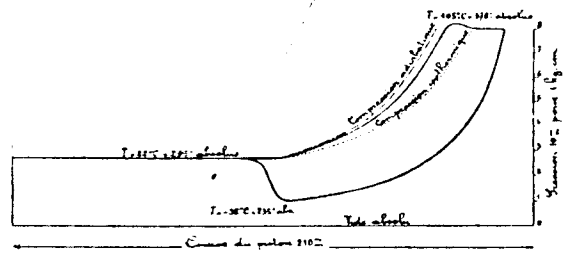
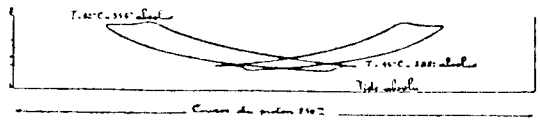
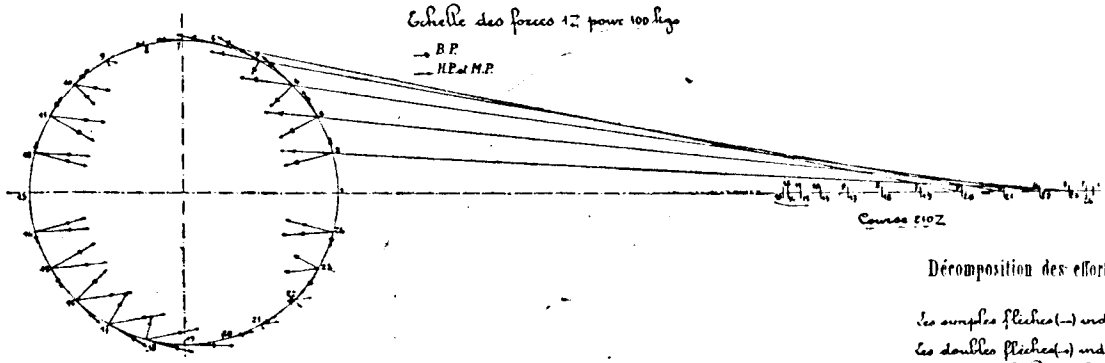


Diagramme B P, position neutre (fig. 39)

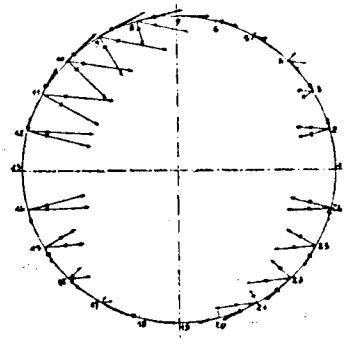


Décomposition des efforts moteurs, admission de 44 % (fig. 40)

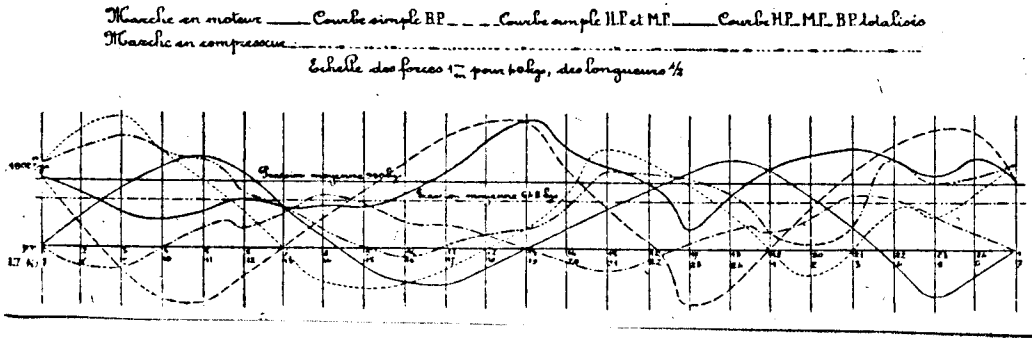


Décomposition des efforts de freinage (fig. 44)

Les simples flèches (→) indiquent les efforts H.P. et M.P.
Les doubles flèches (⇒) indiquent les efforts B.P.
Echelle des forces 1/2 pour 100 kgs



Courbes des efforts tangentiels, admission de 44 % (fig. 42)


Marche en moteur ____ Courbe simple BP _ _ _ Courbe simple H.P. et M.P. ____ Courbe H.P. M.P. B.P. totalisée
Marche en compression
Echelle des forces 1/2 pour 100 kgs, des longueurs 1/2

Détermination de la puissance et de la consommation avec 62 % d'admission au cylindre HP.

Nous avons vu précédemment que le nombre de litres d'air comprimé à la pression initiale de 30 kg. par cm² admis au cylindre HP. d'après le diagramme est de 11.,210.

Le nombre de kilogrammètres développés par tour de manivelle est de :

$$1.380\,\text{kgm.} \times 3{,}1416 \times 210\ \text{mm.} = 910\ \text{kgm.}$$

En tenant compte d'un rendement total minimum de 75 % pour l'ensemble de la machine, à la vitesse de 12 kmh. la puissance développée sera de :

$$\frac{910\,\text{kgm.} \times 2\text{t},1 \times 0{,}75}{75} = 19\,\text{cv. } 11$$

L'effort de traction sera, avec des roues de 0m,500 de diamètre :

$$\frac{910\ \text{kgm.} \times 0{,}75}{1\,\text{m},560} = 437\ \text{kgm.}$$

En tenant compte d'une résistance au roulement de 13 kg. par tonne brute remorquée et un poids de 6.500 kg. pour la locomotive en ordre de marche, nous pourrons remorquer en palier :

$$\frac{437\,\text{kg.} - (6\text{t},5 \times 13\,\text{kg.})}{13\ \text{kg.}} = 27\ \text{tonnes.}$$

Nous admettons que les berlines vides pèsent 300 kg. et que la charge utile de charbon soit de 600 kg., soit 900 kg. pour une berline pleine.

Avec une admission de 62 % au cylindre P. en palier et à la vitesse de 12 kmh. nous pourrons remorquer

$$\frac{27.000\,\text{kg.}}{900\,\text{kg.}} = 30\ \text{berlines.}$$

Sur une pente d'égale résistance de 5mm,5 par mètre en faveur des pleins, le nombre de berlines remorquées sera de :

$$\frac{437}{13 - 5{,}5} = 6\text{t},5 : 0\text{t},9 = 56\ \text{berlines pleines.}$$

Sur cette rampe de 5mm,5, à la vitesse de 12kmh., nous pourrons remorquer un nombre de berlines vides égal à :

$$\frac{437}{13\text{kg.} + 5\,\text{kg.}\,5} = 6\text{t},5 : 0\text{t},3 = 56\ \text{berlines vides.}$$

La consommation théorique par kilomètre, sans tenir compte de la récupération des freinages et de la chaleur développée par la marche en compresseur sera de :

$$\frac{1 : 210 \times 1000}{3{,}1416 \times 0{,}5} = 775\ \text{litres d'air à 30 kg. par cm}^2.$$

Ou :

$775\,\text{l.} \times 30\,\text{kg.} = 23.200$ litres d'air à la pression atmosphérique.

La consommation par tonne utile remorquée sera de :

$$\frac{23.200\,\text{l.} \times 2}{0\text{t},6 \times 56\,\text{b}} = 1.385\ \text{litres à 1 kg. par cm}^2.$$

La contenance utile des réservoirs de la locomotive étant de 1.212 litres et en tenant compte d'une chute de pression de 2 kg. au maximum pour tenir compte des pertes pendant un trajet aller et retour, le chargement se faisant à la pression de 150 kg. par cm², le volume d'air disponible à la pression de 1 kg. par cm² en admettant une pression résiduelle de 28 kg. par cm² dans les réservoirs de la locomotive après un voyage aller et retour, sera de :

$$(1.212\,\text{l.} \times (150\text{kg.} - 2\,\text{kg.}) - (1.212\,\text{l.} \times 28\,\text{kg.}) = 146.000\ \text{lit.}$$

La parcours utile de la locomotive, en mètres, sera de :

$$\frac{146.000\text{l.}}{23.200} = 6.300\ \text{mètres.}$$

Nous déterminerons maintenant l'arrêt d'une rame de 56 berlines avec freinage par marche en compresseur en mettant le levier de changement de marche au cran d'admission de 62 % et sans faire usage du dépiqueur, ce dernier permettant l'arrêt immédiat de la machine.

Nous supposons que l'arrêt doit être produit lorsque la rame de berlines marche à l'allure de 12 kmh. ou 3 m,33 à la seconde.

Poids de la rame de 56 berlines pleines de charbon :

$$(900\,\text{kg.} \times 56) + 6.500\,\text{kg} = 57.500\ \text{kg.}$$

Puissance vive de cette rame à 3 m,33 à la seconde :

$$\frac{57.500\,\text{kg.} \times 3{,}33^2}{2 \times 9{,}81} = 32.500\ \text{kgm.}$$

Sur la pente d'égale résistance de 5 m,5 par mètre, la puissance absorbée par la résistance au roulement sera de : $57.500\,\text{kg.} \times (13\,\text{kg.} + 5\,\text{kg.}5) \times 3{,}1416 \times 0\,\text{m},500 = 672\,\text{kgm.}$

Puissance de freinage par tour de roue, en tenant compte que dans la marche en compresseur le levier de changement de marche étant au cran d'admission de 62 °/₀, donne un effort de 760 kg. comme on l'a vu précédemment :

$$\frac{760 \times 0{,}660}{0{,}75} = 670\ \text{kgm.}$$

Nombre de tours de roue nécessaire pour obtenir l'arrêt de la rame :

$$\frac{32.500}{672 \times 670} = 24{,}2\ \text{tours}$$

Correspondant à une longueur parcourue de :

$$3.1416 \times 0\ \text{m.}\ 500 \times 24\ \text{t.}\ 2 = 37\ \text{m.}\ 800$$

Poids d'une rame de berlines vides :

$$(300\ \text{k.} \times 56) + 6.500 = 23.200\ \text{kg.}$$

Puissance vive de cette rame à 3 m, 33 à la seconde :

$$\frac{23.200\ \text{kg} \times 3.33}{2 \times 9{,}81} = 13.150\ \text{kg.}$$

Puissance absorbée par la résistance au roulement de cette rame sur la rampe d'égale résistance de 5,5 mm. par mètre :

$$23.200 \times (13 + 5{,}5) \times 3.1416 \times 0{,}500 = 670\ \text{kg}$$

Nombre de tours de roue nécessaire pour l'arrêt de cette rame :

$$\frac{13.150}{670 \times 670} = 9\,\text{t},8$$

Soit un parcours de :

$$3{,}1416 \times 0\,\text{m},500 \times 9\,\text{t},8 = 15\,\text{m},300$$

Détermination de la récupération par freinage.

Le nombre de litres d'air comprimé à 30 kg. par cm², récupéré par tour de roue, le levier de changement de marche étant au cran d'admission de 62 °/₀ au cylindre HP. est de 01.557, d'après les diagrammes.

Le nombre de litres d'air à la pression de 1 kg. récupéré par le freinage pendant un voyage aller avec une rame de berlines vides est de :

$$01.,567 \times 9\,\text{t},8 \times 30\ \text{kg.} = 164\ \text{litres.}$$

Le nombre de litres d'air à la pression de 1 kg. récupéré par le freinage pendant un voyage retour avec une rame de berlines pleines est de :

$$01.,557 \times 24\,\text{t},2 \times 30\ \text{kg.} = 403\ \text{litres.}$$

Nous avons admis le minimum de freinage, c'est-à-dire un seul freinage à chaque fin de trajet (dans la pratique il peut y avoir plus de deux opérations de freinage), dans ce cas la récupération totale sera de :

$$4031. + 1641. = 569\ \text{litres.}$$

Ces 569 litres d'air à 1 kg. par cm² sont récupérés sur un parcours de 6.300 mètres, soit :

$$\frac{569}{6{,}3} = 90\ \text{litres par kilomètre.}$$

La consommation par tonne kilométrique brute remorquée avec récupération sera de :

$$\frac{(2.320\,1. - 901.)\ \ 2}{(0\,\text{t},9 \times 56) + (0\,\text{t},3 \times 56)} = 660\ \text{litres d'air à la pression de}$$

1 kg. par cm².

La consommation par tonne kilométrique utile remorquée avec récupération sera de :

$$\frac{(2.320\,l. - 90\,l.2)}{0t,500 \times 56} = 1.330 \text{ litres d'air à la pression de 1 kg. par cm}^2.$$

Dans notre étude, étant donné les grandes difficultés d'appréciation des températures réelles obtenues, nous n'avons pas fait entrer en ligne de compte la chaleur récupérée à la fin et en cours de chaque trajet pendant les périodes de freinage, c'est un facteur qui viendra certainement diminuer encore la consommation.

CONCLUSION

Par cet exposé, nous avons fait ressortir les avantages résultant des dispositions que nous avons adoptées au point de vue de la consommation, laquelle est d'une grande importance non seulement parce qu'on réalise une économie qui diminue le prix de revient de la tonne kilométrique utile, mais aussi parce qu'elle permet un rayon d'action plus grand à la machine pour un même encombrement, on a donc double intérêt à avoir une locomotive aussi économique que possible.

Certains constructeurs ont adopté, et nous-mêmes dans le début, des dispositifs aussi dispendieux que compliqués pour le réchauffage par l'eau surchauffée, pour en arriver finalement à l'emploi de la chaleur de l'air ambiant, moyen dont l'efficacité relativement faible était loin de valoir notre dispositif de réchauffage par la chaleur récupérée par la marche en compresseur pour l'arrêt à chaque fin de trajet dans un sens ou dans l'autre.

La sécurité est absolue par l'emploi de notre dépiqueur pour la mise en marche et l'arrêt instantané des convois, ce qui permet, le mécanicien étant absolument sûr de sa machine, d'adopter une vitesse moyenne de quinze kilomètres à l'heure et d'augmenter considérablement le rendement utile pour une même période de travail.

Par la disposition d'un treuil à l'avant de la machine, on pourra prendre les berlines dans les galeries latérales d'abatage dont la faible section ne permet pas l'accès des locomotives, nous pensons pouvoir arriver ainsi à supprimer totalement les chevaux au fond.

Nous nous sommes efforcés, pour notre nouvelle locomotive, en nous inspirant des besoins actuels de l'industrie minière, de réunir tous les perfectionnements connus jusqu'à ce jour. et, tout en étant d'une construction des plus simples, d'une sécurité absolue, d'utiliser d'une façon rationnelle l'air comprimé sous un encombrement des plus réduits.

Note de l'auteur. — Des machines semblables sont en cours d'exécution aux ateliers de la Compagnie de Fives-Lille pour les mines de sels de potasse Reichsland, à Wittenheim (Haut-Rhin).

Utilisation de la vapeur d'échappement dans les machines à mouvement alternatif pour la production de l'air comprimé à haute pression.

L'usage de l'air comprimé à haute pression se répandant de plus en plus dans les mines, devenant même indispensable pour les transports souterrains par locomotive à air comprimé, il nous a semblé tout naturel de chercher à le produire au moyen des vapeurs d'échappement des machines d'extraction ou auxiliaires.

Nous avons donc été amenés à étudier un compresseur actionné directement par un cylindre utilisant la vapeur à basse pression.

Dans notre ensemble, le compresseur d'air est de notre type ordinaire à quatre relais, le cylindre à vapeur basse pression se trouve fixé sur le même socle et intercalé entre les cylindres à air basse et haute pression, le diamètre varie entre 2,5 et 2,6 de la course.

La vitesse que nous avons adoptée est favorable pour éviter les refroidissements car la température des parois s'élève en fonction directe de la vitesse moyenne des

pistons.

Quant à la petite course imposée, nous savons qu'à égalité de volume engendré deux cylindres sont équivalents et produisent le même travail quel que soit le rapport entre les courses et les diamètres, sous réserves des différences pouvant résulter des espaces nuisibles et de l'action des parois où la pratique démontre que, pour un même volume de cylindres, plus la longueur est petite, moins l'action des parois est grande.

Notre cylindre à vapeur comporte deux chambres (v. FIG. 45-46) séparées par une troisième plus petite formant réservoir d'admission et recevant les distributeurs.

Cette chambre porte en son milieu un passage formant presse-étoupes pour le passage de la tige des pistons, et dont le bourrage est constitué par une série de boîtes annulaires recevant des segments en fonte agissant à frottement doux sur la tige. Ces boîtes portent en outre des cavités annulaires communiquant avec une tuyauterie d'huile sous pression qui sert au graissage de la tige des pistons.

Les fuites de vapeur qui pourraient se produire sont absorbées successivement par les cavités où elles rencontrent l'huile sous pression qui constitue un joint étanche tout en assurant un graissage des plus efficaces.

Chacune des deux chambres extrêmes, c'est-à-dire les deux cylindres moteurs extérieurs au réservoir d'admission sont fermés par des fonds formant entretoises, boulonnés sur les brides extrêmes des cylindres à vapeur et sur ceux basse et haute pression d'air comprimé. Chacun de ces fonds porte en son milieu un passage pour la tige des pistons et se trouve muni d'une chambre d'eau pour en assurer le refroidissement et combattre l'échauffement résultant de la compression d'air.

Dans chacun de ces cylindres se meut un piston fixé sur la tige commune aux pistons de compresseurs.

L'échappement s'effectue, comme pour les machines équicourant, par des ouvertures ou orifices que découvrent les pistons à chaque fin de course.

Par la disposition adoptée pour l'admission et l'échappement, nous réduisons au minimum les variations de température des parois métalliques, les pertes de calorique et de condensations dans l'intérieur des cylindres, les pertes souvent considérables par les fonds, jointes à celles des rentrées et sorties alternatives des tiges des pistons se trouvent supprimées ; quant aux fonds extrêmes, ils sont toujours en contact sur une face avec la vapeur d'échappement à la pression du condenseur, sur l'autre avec de l'eau de circulation du compresseur, il y a donc peu de différences de température ; du reste, les condensations ne sont pas à craindre par suite de la disposition des orifices d'échappement.

Dans les machines ordinaires, le cylindre est mis en communication avec le condenseur pendant une course entière, moins les avances, ce qui refroidit considérablement les parois, tandis que dans notre disposition, cette communication ne dure que juste le temps du passage aller et retour du piston sur les lumières d'échappement, soit environ deux dixièmes de la course à l'aller et autant au retour (voir FIG. 47-48).

Le volume de vapeur à la pression du condenseur emmagasiné dans le cylindre est ramené en fin de course par la compression à une température et par suite à une pression sensiblement égales à celles de la vapeur d'admission ; il en est à peu près de même des parois à l'introduction ; la vapeur arrive dans un milieu de même température, résultat impossible à obtenir dans les machines à un seul piston où il se produit une condensation de vapeur vive et par suite une importante perte de travail jusqu'à ce que l'équilibre de température se produise.

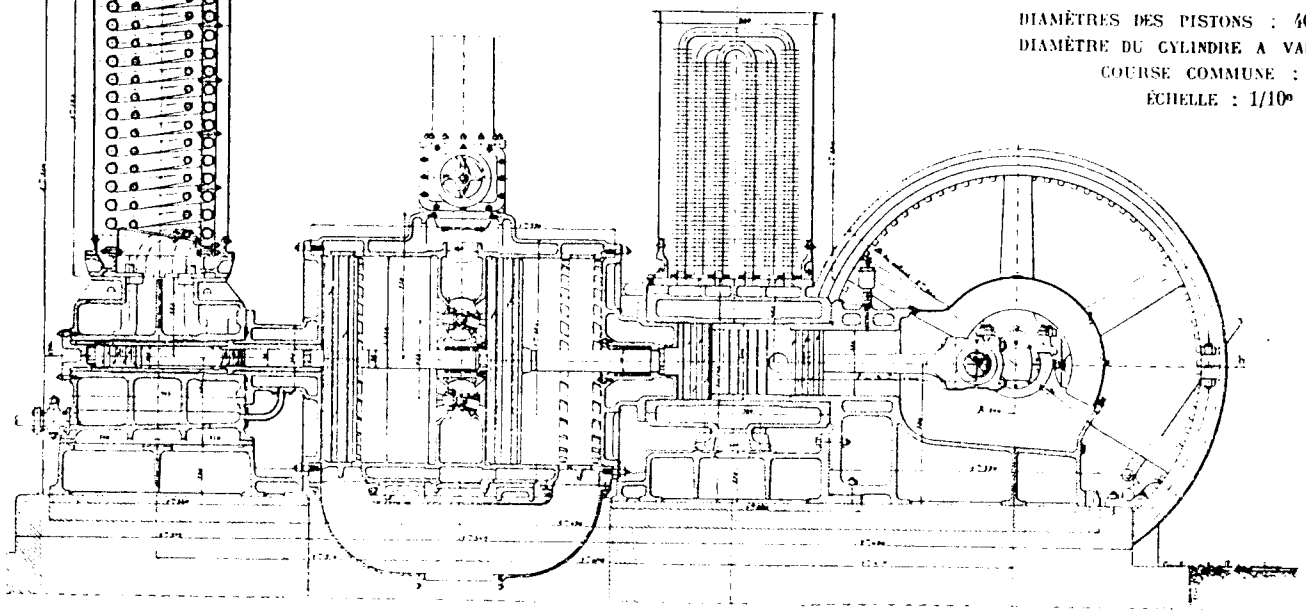
L'utilisation de vapeur dans une machine, et plus particulièrement de vapeur à basse pression, étant une fonction déterminée de la différence entre les températures initiales et finales aux cylindres, de l'étendue des surfaces exposées aux variations des températures extérieures et intérieures, de la vitesse des pistons, nous nous sommes efforcés de grouper mutuellement ces conditions dans une étroite dépendance des plus favorables au rendement thermodynamique de notre

Compresseur d'air haute pression a Commande directe par Cylindre a vapeur basse pression

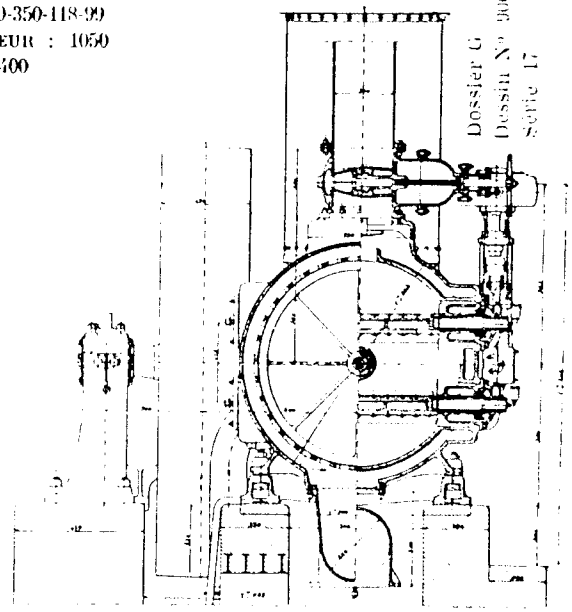
Type à quatre relais pour 165 kg par cm² — Disposition et distribution brevetées S. G. D. G.

Coupe longitudinale suivant A B. (fig. 45)

DIAMÈTRES DES PISTONS : 400-350-118-99
DIAMÈTRE DU CYLINDRE A VAPEUR : 1050
COURSE COMMUNE : 400
ÉCHELLE : 1/10e



Coupe G. D. E. F. (fig. 47)



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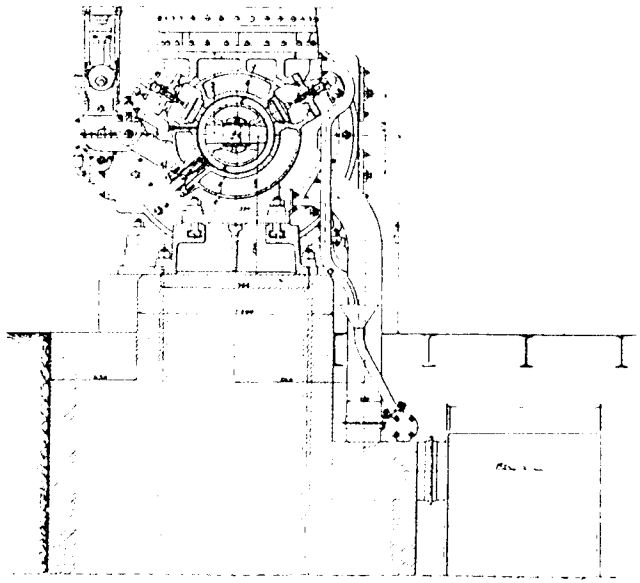
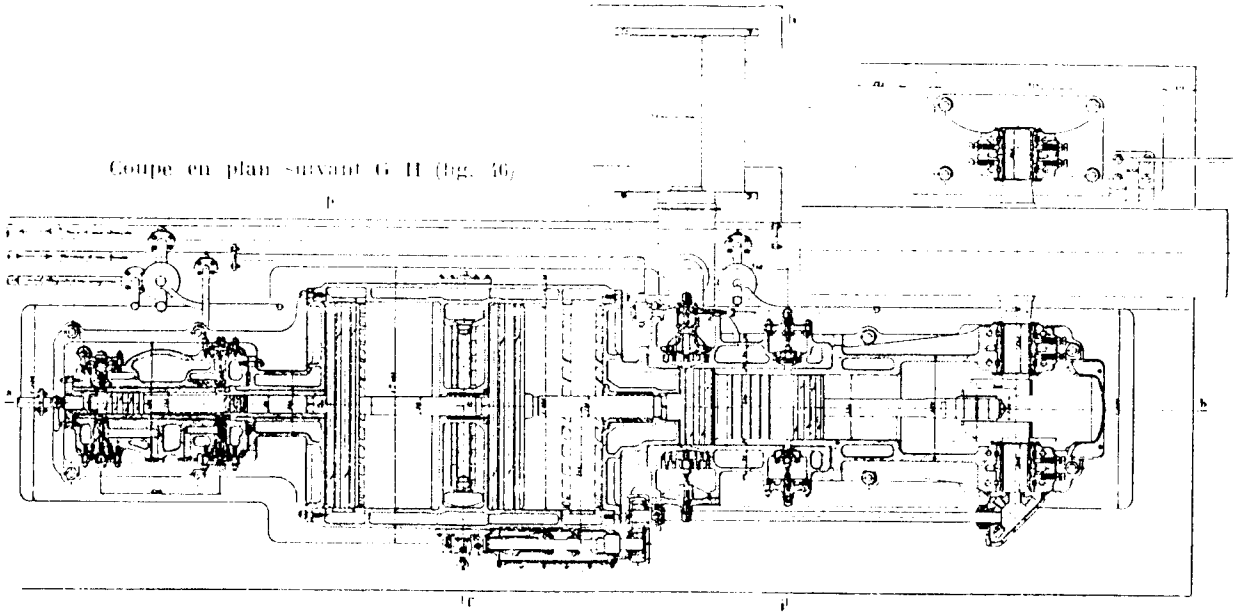
Série 17

Coupe en profil suivant I J (fig. 48)



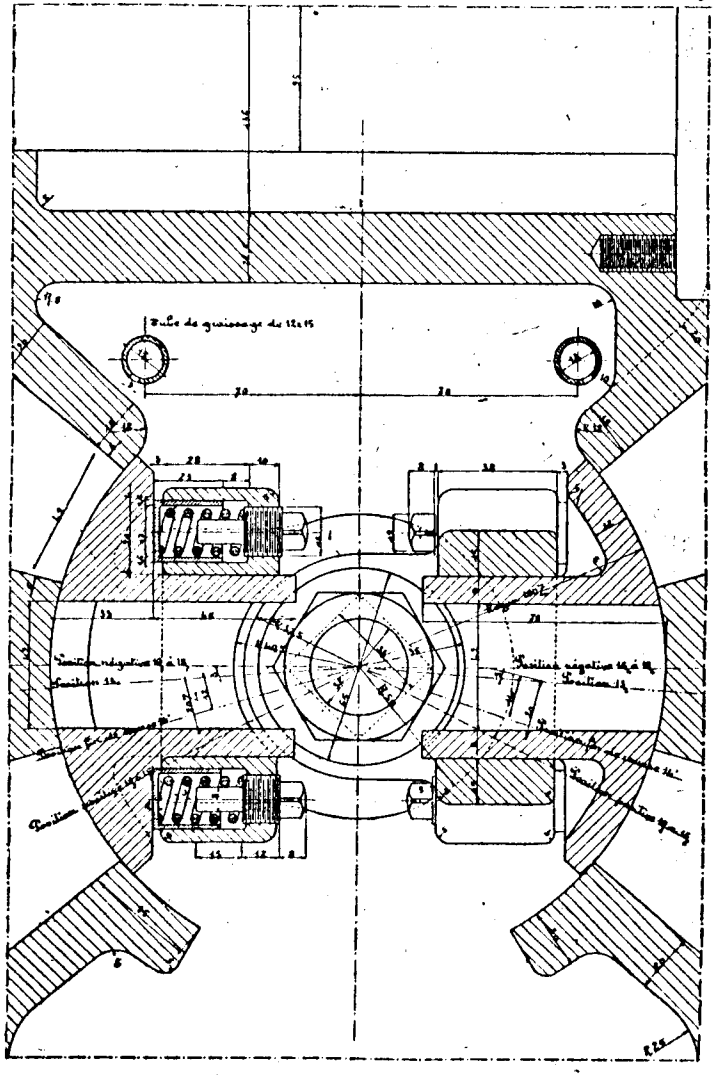
Coupe en plan suivant G H (fig. 46)



machine, comme le montrent du reste les diagrammes dynamiques et entropiques que nous en avons tracé.

Par contre, les inconvénients que l'on peut nous reprocher sont l'augmentation des masses en mouvement et des frottements par l'adjonction d'un second piston et par la différence d'accès du presse-étoupes de la chambre médiane.

Le premier peut être combattu par une construction légère



Détail des obturateurs (fig. 49)

et soignée qui nous permet de réduire au minimum le poids des pistons par le graissage sous pression qui atténue autant que faire se peut les frottements dans les calfats; en tous cas les avantages que procure notre disposition au point de vue de l'utilisation de la vapeur et du rendement calorifique compensent largement l'action nuisible de ce poids complémentaire.

Quant au second, la construction que nous avons adoptée donne toute sécurité sanctionnée par une longue pratique ; la réfection de ce presse-étoupes est fort rare et s'opère très rapidement, si la nécessité s'en fait sentir, lors du changement des segments du piston du cylindre à air, haute et pression moyenne, environ une fois l'an.

Etant donné les grandes sections qui sont nécessaires pour les distributeurs par suite de la basse pression entraînant une faible vitesse de la vapeur, nous avons adopté les distributeurs rotatifs à doubles lumières (voir Fig. 49), qui nous permettent de réaliser des vitesses de 14 à 15 mètres par seconde à l'admission, et de 7 à 8 mètres par seconde pour l'échappement qui s'opère sur toute la périphérie des extrémités des cylindres sections absolument impossibles à obtenir avec les organes ordinaires de distribution généralement employés.

Les distributeurs d'admission placés dans la chambre médiane sont au nombre de quatre, deux par cylindre, groupés sur un même axe concentrique.

Les tables ou glaces d'obturateurs sont placés deux à deux sur chaque face de la chambre de distribution, elles sont à deux lumières; les obturateurs sont montés à frottement doux sur un cadre et pressés sur leur glace par une série de petits ressorts à boudin exerçant une pression totale de 25 à 30 kg. supérieure à celle exercée par la vapeur d'admission, de façon à éviter toute fuite.

Les figures ci-jointes montrent très distinctement le montage des cadres de commande des obturateurs et les dispositifs adoptés pour la sortie des axes et leur graissage. Il sont terminés à leur extrémité de sortie par deux manivelles qui sont conjuguées par des bielles d'accouplement munies d'un réglage par double filetage à pas contraires avec contre.

écrous de sécurité. Les deux manivelles sont commandées par deux bielles munies du même dispositif de réglage et attelées à deux balanciers concentriques l'un à l'autre, oscillant autour d'un même axe fixé dans un support venu de fonte sur le couvercle des boites des ressorts de rappel.

Un arbre longitudinal placé et maintenu dans des supports le long du compresseur, commandé par un relai d'engrenages égaux, tourne à la même vitesse que l'arbre du compresseur. Sur cet arbre se trouve placé un manchon porte-came, qui peut coulisser longitudinalement tout en recevant le mouvement de rotation de l'arbre au moyen d'un clavetage convenablement disposé.

Les cames de distribution sont profilées de façon à répondre aux conditions de notre distribution, conformément à l'épure établie.

Sur ces cames viennent rouler des galets, dont le contact est assuré par des poussoirs munis de ressorts de rappel, lesquels commandent les balanciers et par les renvois de bielles, les obturateurs de distribution.

Sur l'arbre des cames se trouve calé un engrenage conique qui commande l'arbre vertical d'un régulateur qui agit sur le distributeur de la machine à vapeur et sur le dispositif qui soulève la platine de la soupape d'aspiration de premier relais du compresseur, et supprime le débit lors de la compression.

A cet effet, sur l'arbre du régulateur se trouve monté un manchon qui porte en son milieu une douille portant deux tourillons reliés par bielles à un levier d'équerre qui commande le mouvement de translation horizontale du manchon porte-cames et, par suite, fait varier les degrés d'admission et de détente, suivant l'allure de la machine asservie au régulateur.

Sur le bâti du régulateur se trouve à droite un cylindre portant à sa base un raccord qui assure sa communication avec le réservoir haute pression ou refoule le compresseur. Ce cylindre reçoit un piston qui transmet son mouvement à un levier muni à l'une de ses extrémités d'un contre-poids de réglage et à l'autre se trouve articulé sur un axe supporté par un bossage venu de fonte avec le bâti du régulateur. Entre cet axe et le contre-poids, à une distance dans un rapport déterminé, se trouvent deux tourillons engagés dans les têtes fendues de deux bielles attelées à leur base sur la bague du manchon du régulateur, lequel peut agir sur le manchon porte-cames, sans effet sur le compresseur par suite de la fente des têtes de bielles.

Si la pression d'air comprimé dépasse la limite pour laquelle le contre-poids du levier est réglé, et qui correspond à la pression maximum de compression, le piston monte dans le cylindre jusqu'à ce qu'il vienne découvrir un petit orifice qui met à l'échappement à l'air libre, après avoir soulevé le levier puis le manchon du régulateur, en agissant sur la commande de la distribution de façon à ralentir l'allure jusqu'à ce que la pression baisse dans le réservoir et que la machine reprenne son allure normale, tandis que, de son côté, le régulateur d'air comprimé a produit son action sur le compresseur.

Sur l'arbre longitudinal placé à droite de la commande du régulateur se trouve disposée une pompe à huile à excentrique pour le graissage sous pression par un raccord fileté placé sur le côté, et un tuyau qui refoule l'huile dans un réservoir à départs multiples en charge sur les organes en mouvement.

Les mécanismes de commande de la distribution et du régulateur sont renfermés dans un même carter étanche les mettant à l'abri des poussières et permettant leur barbotage dans un bain d'huile.

L'arrivée de vapeur venant de l'accumulateur peut se faire, soit à la partie supérieure de la chambre d'admission, soit à la base sur l'un des côtés ; la vapeur circule autour des cylindres dans une enveloppe prévue à cet effet, et, par une tubulure à collet relevé pour éviter les entraînements d'eau, pénètre dans la chambre de distribution.

Près de chaque fond des cylindres, contre les cloisons de la chambre de distribution, est placée une soupape de sûreté mettant en communication le cylindre avec la chambre d'admission de vapeur dès que la pression pour une cause imprévue devient plus élevée dans les cylindres que dans l'admission.

Quand la vapeur arrive par la partie supérieure des cylindres, il faut avoir soin de disposer un écran bombé muni de rebords à une certaine distance de la tubulure d'admission afin d'éviter qu'à l'ouverture de la vanne d'admission l'eau de condensation qui se trouve dans la conduite ne vienne à s'introduire dans la chambre de distribution.

Sur le corps de la vanne, légèrement au-dessus du siège, on fixe un purgeur avec une tuyauterie d'évacuation d'eau condensée.

Il faut avoir soin d'ouvrir ce purgeur avant l'ouverture de la vanne, attendre un certain temps, et ne le fermer qu'immédiatement après l'ouverture en grand de la vanne d'admission.

Sur un support placé latéralement à la vanne se trouve un taquet-clef lequel, par un renvoi convenablement disposé, commande l'ouverture des purgeurs des cylindres lors de la fermeture de la vanne, l'ouverture de celle-ci ne peut se faire qu'après la fermeture des dits purgeurs.

La chambre d'admission de vapeur porte à la partie inférieure une tubulure à laquelle on peut adapter un purgeur automatique et y monter un siphon qui sera placé dans un puits d'évacuation de 15 mètres de profondeur.

Quand l'installation le permet, il faut placer le niveau inférieur de l'enveloppe des cylindres sur le même plan que le niveau du plan d'eau du compartiment inférieur de l'accumulateur de vapeur, et faire un retour direct de la purge de l'enveloppe et de la chambre de distribution dans l'accumulateur en interposant un vase d'expansion et un clapet de retenue convenablement placé pour empêcher les retours d'eau de l'accumulateur vers les cylindres.

L'eau condensée varie entre 1/10e et 1/15e de la consommation de vapeur.

VARIANTE

Pour rendre plus facile la visite des pistons, des calfats et de tous les organes du mouvement, nous avons prévu une deuxième disposition qui présente en outre des avantages particuliers.

Dispositions générales. — Comme le montre les figures ci-jointes 50-51-52-53 le compresseur d'air et le cylindre à vapeur sont séparés et disposés respectivement à l'avant et à l'arrière d'un bâti formant glissière.

La tige des pistons du cylindre à vapeur actionne directement les pistons du compresseur d'air par l'intermédiaire d'une crosse entretoise coulissant sur deux glissières du bâti.

La régularisation du mouvement alternatif des pistons est obtenue par un volant léger calé sur un arbre à manivelle porté par deux paliers, et le maneton de cette manivelle tourne dans un coulisseau qui glisse entre deux glissières verticales de la crosse entretoise.

Par cette disposition, l'arbre, le maneton et le coulisseau n'ont à transmettre que les efforts emmagasinés ou restitués par le volant. Le bâti, solidement ancré et boulonné dans la maçonnerie, réunit les deux groupes à air et à vapeur.

Distribution — L'arbre manivelle commande l'arbre de distribution par l'intermédiaire de deux engrenages coniques égaux. Dans cette disposition, une seule came disposée sur un maneton coulissant sur l'arbre assure l'ouverture des distributeurs d'admission et d'échappement par deux mécanismes symétriques.

Le déplacement de la rampe de la came sur l'arbre de distribution règle ou supprime l'ouverture des distributeurs, comme dans la disposition précédente.

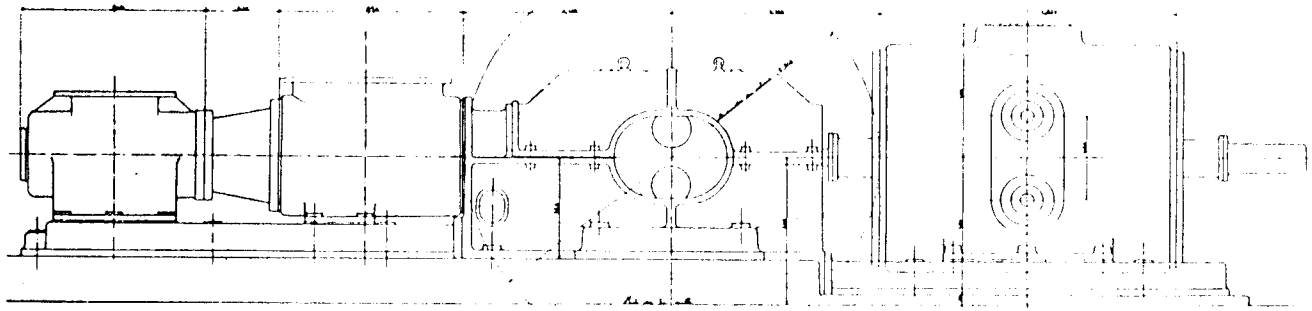
Mais, dans le but de réduire l'importance du régulateur et les réactions sur cet appareil, nous avons soumis le déplacement du maneton de la came à l'action d'un piston à air comprimé.

Un tiroir distribue l'air comprimé sur l'une ou l'autre face du piston, à la demande du régulateur, qui ne doit ainsi fournir qu'une très faible énergie et peut agir rapidement avec toute efficacité.

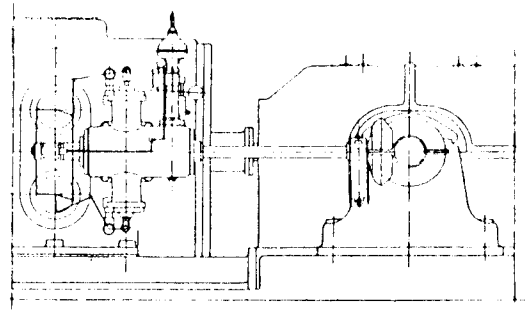
L'air comprimé du deuxième relais agit sur les faces du piston par l'intermédiaire d'une capacité remplie d'huile dont la vitesse d'écoulement est réglable par deux pointeaux.

Compresseur d'air à haute pression à commande directe par cylindre à vapeur à basse pression.
Type à quatre relais. — Système Leroux. — Echelle 1/10e.

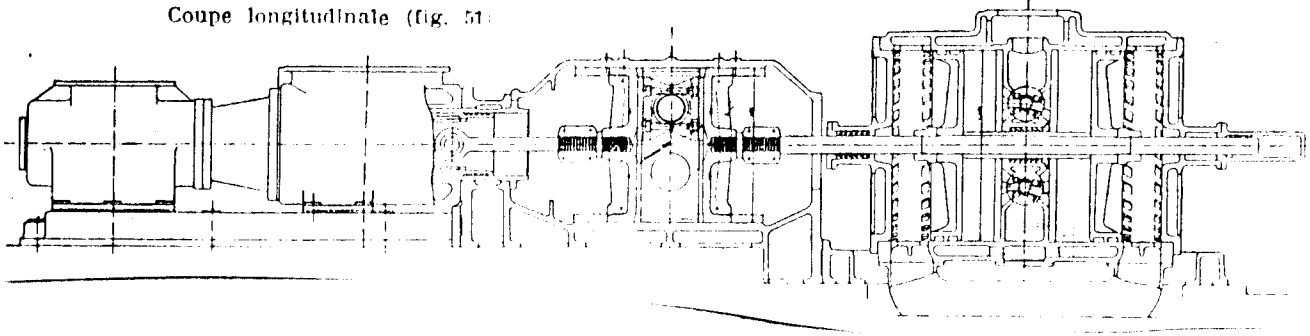
Elévation (fig. 50)



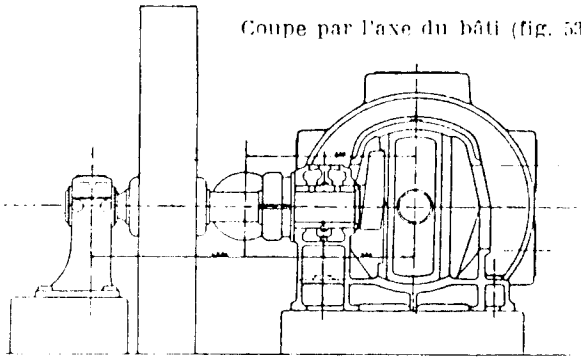
Vue extérieure de la distribution (fig. 52)



Coupe longitudinale (fig. 51)



Coupe par l'axe du bâti (fig. 53)



Un dispositif de sécurité agissant lorsque la pression d'air a atteint la limite maximum est prévu sur le régulateur.

Visites. — Pour les visites du piston arrière à vapeur et des pièces du mouvement, la glissière supérieure du bâti est démontable, des manchons en deux parties boulonnées assemblent les tiges de piston à la crosse par des attaches, de façon à permettre le réglage du jeu des pistons à fond de course.

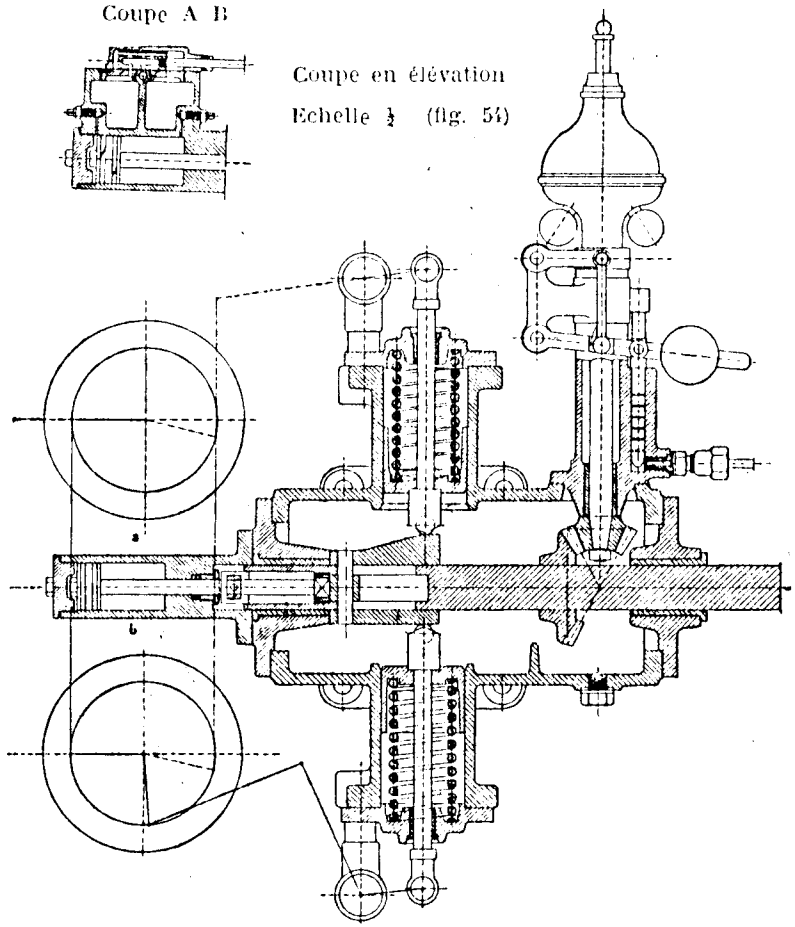
Le piston avant à vapeur est facilement accessible ainsi que les diverses garnitures et les organes de distribution.

Etude d'une machine à mouvement alternatif utilisant la vapeur à basse pression.

Pour fixer les idées, nous avons pris comme exemple la puissance la plus généralement employée et correspondant aux données ci-dessous :

Données. —	Puissance effective de la machine.....	125 ch.
	Nombre de tours par minute....	160
	Course imposée du piston.....	400 mm.
	Vitesse de la vapeur (admission d'échappement).	15 à 16 m. s.
	Pression absolue de la vapeur...	950 gr.
	Pression absolue du condenseur.	65 gr.

Dispositif de commande de la régulation de la distribution par servomoteur à air comprimé asservi au régulateur. - Disposition brevetée S.G.D G.

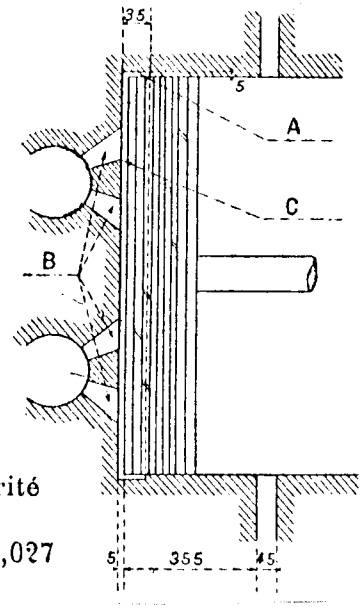


Section du cylindre

$$\frac{125 \times 75}{(0{,}950\text{-}0{,}065 \times 160 \times 0{,}4 \times 0{,}75 \times 0{,}8)} = 827.600 \text{ mm}^2$$

Admettons pour rendement thermique 0,80 et rendement mécanique 0,75.

Diamètre de la tige, 95 mm. correspondant à une section $\frac{3{,}14 \times 95^2}{4} = 7.088 \text{ mm}^2$.



Diamètre du cylindre et pour toute sécurité

$$\sqrt{\frac{(827.600 + 7.088) \times 4}{3{,}1416}} = 1{,}027$$

soit 1,050 par excès.

Section correspondante $\frac{1{,}050^2 \times 3{,}14}{4} = 865.901$, soit une section utile de $865.901 - 7.088 = 858.813 \text{ mm}^2$.

Volume d'introduction à chaque course du piston avec admission de 85/100 $= \frac{858.813 \times 400 \times 85}{100} = 291.996.420 \text{ mm}^3$.

Section des lumières d'admission et d'échappement pour une vitesse de 15 ms. $\frac{291.996.420 \times 100 \times 160}{85 \times 30 \times 15.000} = 129.775 \text{ mm}^2$ correspondant pour l'admission à une longueur de lumières

$$= \frac{129.775}{42} = 3{,}000.$$

D'après notre étude nous avons 2,940 suffisant pour une vitesse de 15 à 16 m. s.

L'espace nuisible se décompose en trois parties comme suit :

La partie A couronne d'évidement

$$(882.473\text{-}865.901) \times 32 = 530.304.$$

La partie B lumière d'admission

$$\frac{(48 + 70)}{2} \times 42 \times 2.940 = 7.285.320.$$

La partie C espace du piston à fond de course

$$858.813 \times 5 = 4.294.065.$$

Soit un total de 12.109.689 mm³.

Volume total à partir de l'ouverture d'échappement

$$858.813 \times 355 + 12.109.689 = 316.988.304 \text{ mm}^3.$$

Rapport du volume total au volume de l'espace nuisible

$$\frac{316.988.304}{12.109.689} = 26,1$$

Volume à partir duquel la pression est = à 950 gr.

$$\frac{316.988.304 \times 65}{950} = 21.688.667 \text{ mm}^3.$$

Course restant à parcourir pour le passage au point mort

$$\frac{21.688.667 - 12.109\,689}{858.813} = 11 \text{ mm},1 \text{ (point 13)}.$$

Trace du diagramme X O X ligne du vide absolu sur laquelle nous portons les déplacements du piston à l'échelle de 1/2. Sur l'ordonnée O Y les pressions à l'échelle de 5 mm. pour 100 gr. (Fig. 55-56).

La droite A B ligne de pression atmosphérique.

Le piston commence sa course ascendante au point 1, de 1 à 2 la pression est égale à celle du condenseur 65 gr. par suite de l'ouverture d'échappement.

Au point 2, l'échappement est fermé, la contre-pression commence.

Déterminons sa valeur aux différents points de la course.

Point 3 $= \frac{65 \times 316.988.304}{269.753.589} = 76$ gr. 3. Point 4 $= \frac{65 \times 316.988.304}{235.401.069} = 87,5.$

Point 5 $= \frac{65 \times 316.988.304}{201.048.549} = 102$ gr. Point 6 $= \frac{65 \times 316.988.304}{166.696.029} = 123.$

Point 7 $= \frac{65 \times 316.988.304}{132.343.509} = 155.$ Point 8 $= \frac{65 \times 316.988.304}{97.990.989} = 210.$

Point 9 $= \frac{65 \times 316.988.304}{63.638.469} = 323.$ Point 10 $= \frac{65 \times 316.988.304}{46.462.209} = 441.$

Point 11 $= \frac{65 \times 316\,988.304}{378.740.079} = 544.$ Point 12 $= \frac{65 \times 316.988.304}{29.285.949} = 703.$

En 13 la contre-pression atteint son maximum qui ne peut dépasser la pression d'admission.

L'admission commence du reste à ce point 13.

L'avance à l'admission correspond à une course de 11 mm,1 du piston.

La course descendante commence en 14 pour se terminer en 16, représentant 85 % de la course.

Pour compenser les étranglements possibles, nous infléchissons la courbe vers le vide absolu.

Au point 16 la pression commence à baisser, en 17 l'échappement commence à s'ouvrir.

La pression à l'intérieur du cylindre au moment de fermeture d'échappement est de 65 gr.

Pour déterminer la pression moyenne déterminons la surface de notre diagramme et divisons par la course

$$\text{soit : } \frac{271.170}{400} = 0 \text{ kg},6.779 \text{ par cm}^2.$$

Puissance de la machine d'après le diagramme théorique avec rendement de 0,75.

$$\frac{0,6779 \times 858.813 \times 0,4 \times 160 \times 0,75}{30 \times 75} = 124 \text{ chevaux } 01.$$

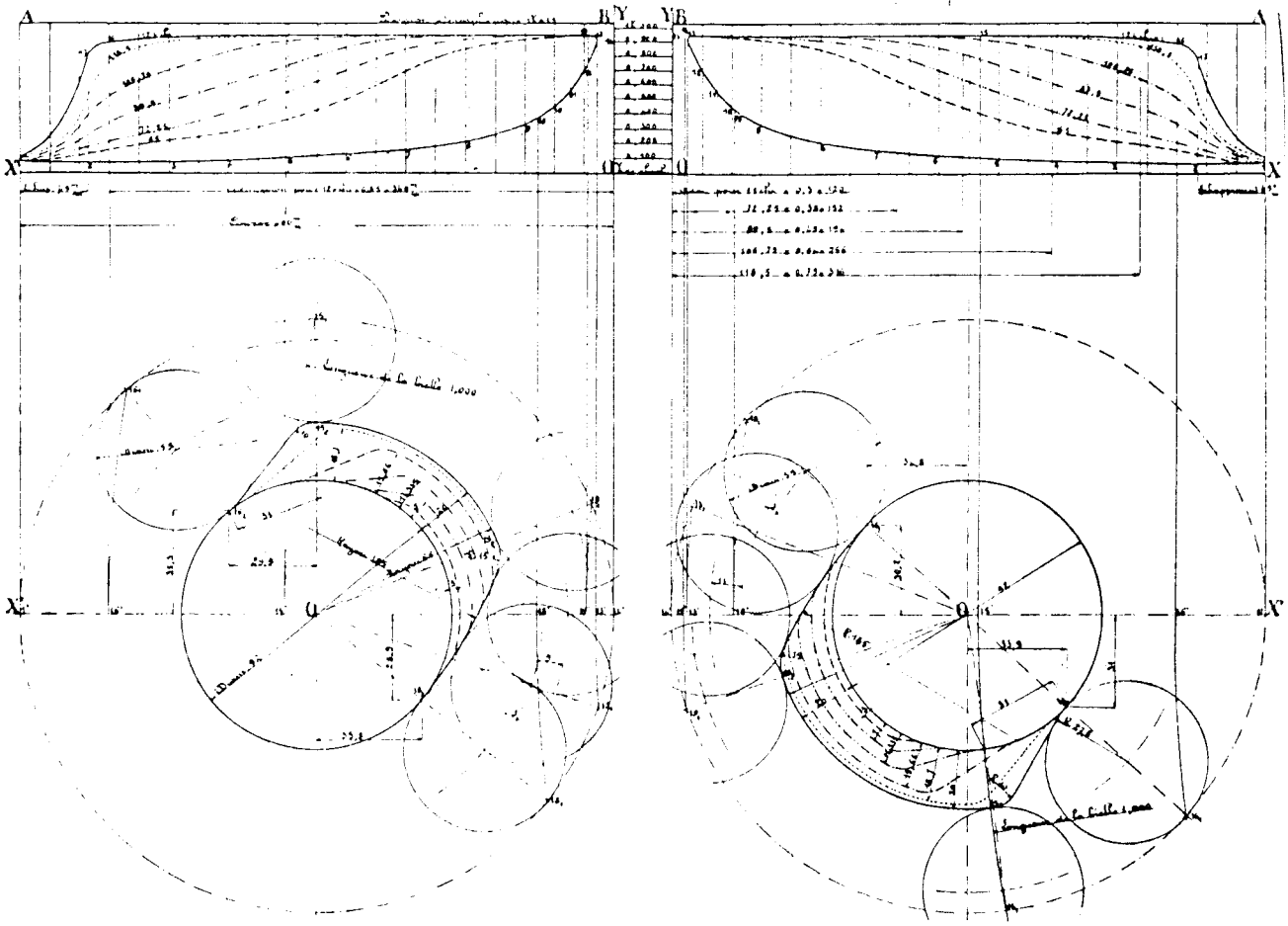
Consommation théorique de vapeur par heure.

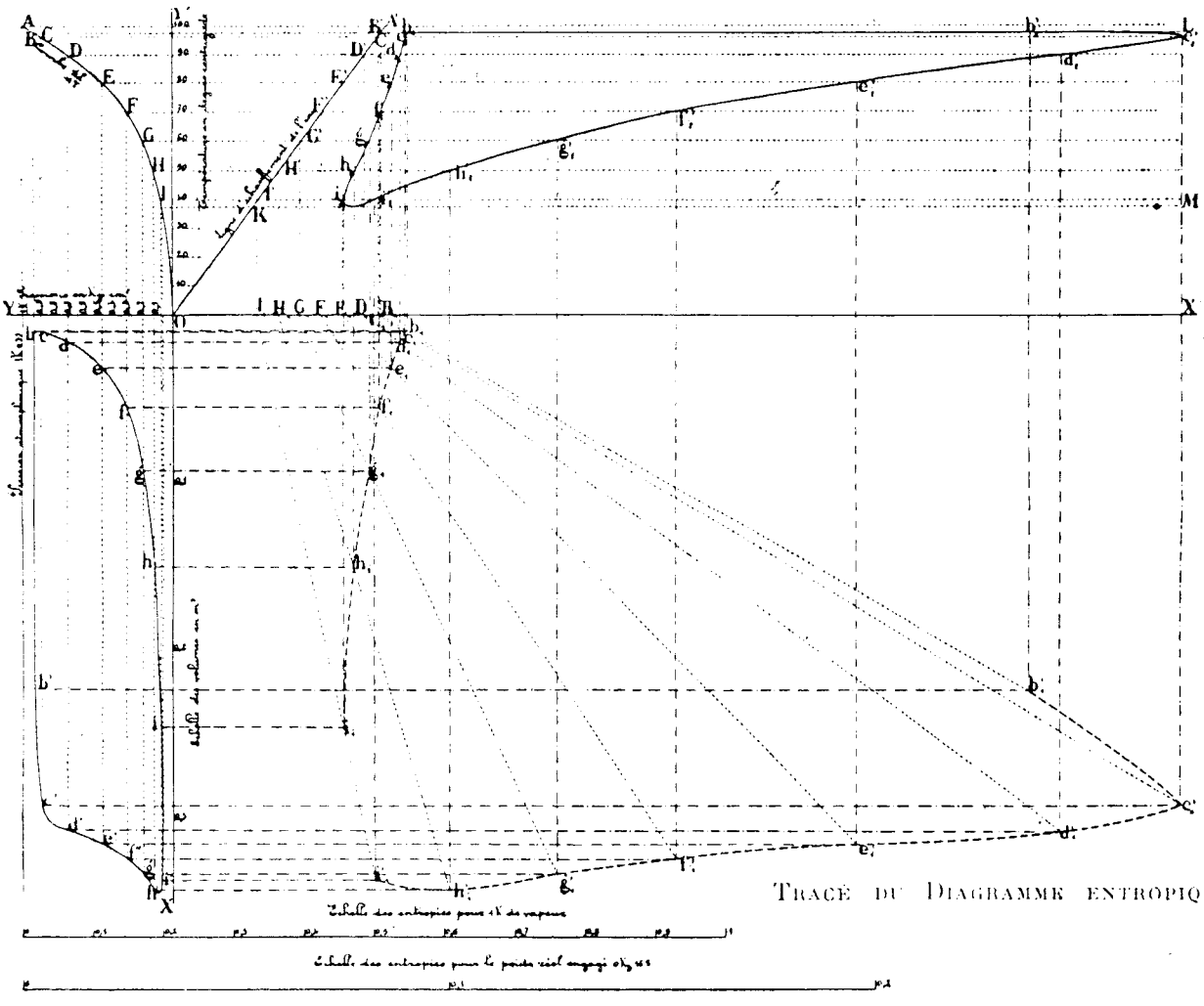
$858.813 \times (3,4\text{-}0,111) \times 160 \times 2 \times 60 = 5.424.949$ litres ou 5.424 m³,349.

$$\text{Soit : } \frac{5.424,949}{124,01} = 43 \text{ m}^3,75 \text{ ou ou } 0,562 \times 43,75 = 24 \text{ kg},58$$

par cheval heure.

Tracé des Diagrammes et des Cames (fig. 55)





Tracé du Diagramme entropique (fig. 56)

Ce qui nous donne une consommation horaire de

$$24{,}58 \times 124{,}01 = 3.048 \text{ kg.}$$

Trace des cames et des positions correspondantes des obturateurs. — La course ascendante correspond au point 1 du diagramme ou en 1' de la manivelle.

De 1' en 18_1 le galet roule sur la partie négative de la came et l'obturateur est immobile.

En 13 du diagramme l'admission commence.

De 19_1 en 15_1 l'admission est totalement ouverte.

De 15_1 en 16_1 l'admission se ferme.

L'ouverture totale de l'obturateur est de 28 degrés correspondant à une hauteur de came de 20 mm.

En 13 du diagramme menons une perpendiculaire à X' X' y déterminant 13_1 de ce point avec un rayon égal à la longueur de la bielle ; nous traçons un arc de cercle coupant la circonférence décrite par la manivelle en 13_1 O et le galet qui devra être tangent à une courbe distante de 49 mm. de l'axe O correspondante à une levée de came de 3 mm., soit de 11 mm,1 de la course du piston prévus pour que la contre-pression soit toujours en dessous de la pression d'admission.

Avec un rayon admis de 185 mm. traçons une tangente aux galets 13_1 et 18_1 que détermine la montée de la came que nous raccorderons par un congé de 15 mm. à la courbe 19_2-15_2 de pleine admission.

En 15_1 nous traçons le galet tangent à la courbe 19_2-15_2.

En 15_2 avec un rayon de 10 mm. nous décrivons un arc de cercle tangent au galet 15_1.

Au point 16, l'obturateur doit être fermé, le galet se trouve en 16_2 de la courbe négative de la came.

De 16 du diagramme menons une perpendiculaire 16-16' à l'axe.

De 16_1 avec un rayon égal à la longueur de la bielle, nous traçons un arc de cercle coupant la circonférence décrite par la manivelle au point 16_1 que nous joignons au centre O.

En 16_2 rencontre de la courbe négative ; nous traçons la circonférence du galet, menons une tangente commune à cette circonférence et au congé de 10 mm., nous obtenons la descente de la came 15_2-16_2 qui représente la fermeture des lumières.

Diagramme entropique. — Sur l'abcisse O X nous portons (FIG. 56), les volumes à l'échelle de 582 mm. pour 1 m³, sur l'ordonnée O Y les pressions à l'échelle de 5 mm. pour 100 grammes, sur l'abcisse O X' les entropies à l'échelle de 240 mm. pour l'unité, sur l'ordonnée O Y' les températures à l'échelle de 1 mm. pour un degré.

Dans la partie inférieure de gauche X O Y nous traçons notre diagramme dynamique.

Sur l'ordonnée O Y aux points marquant les différentes températures nous traçons des abcisses par rapport au diagramme entropique.

Sur l'ordonnée O Y aux points indiquant les pressions correspondantes aux températures, nous traçons des abcisses par rapport au diagramme dynamique lesquelles rencontrent les premières aux points A B C D E F G H I qui nous donnent

$$\text{la courbe } \frac{d\,P}{d\,T}.$$

Sur l'abcisse O X nous portons l'entropie d'échauffement de l'eau (0,314 %) 73 mm. à l'échelle adoptée, nous élevons une ordonnée qui rencontre la ligne de 100° au point A^0 en joignant au point O, nous obtenons la ligne d'échauffement de l'eau.

Des points A' B' C' D' E' F' G' H' I' correspondants aux températures, abaissons les ordonnées à O X qui déterminent A_1 B_1 C_1 D_1 E_1 F_1 G_1 H_1 I_1 nous menons des parallèles aux tangentes des points correspondants de la courbe $\frac{d\,P}{d\,T}$.

De $b.\ b'c\ c'd\ d'e\ e'f\ f'g\ g'h\ h'i\ i'$ menons des ordonnées à O X jusqu'à la rencontre des lignes de températures

correspondantes, nous obtenons les courbes $b_1\ c_1\ d_1\ e_1\ f_1\ g_1\ h_1\ i_1$ et $b'_1\ c'_1\ d'_1\ e'_1\ f'_1\ g'_1\ h'_1\ i'_1$; de ceux-ci menons des ordonnées qui déterminent les points $b_2\ c_2\ d_2\ e_2\ f_2\ g_2\ h_2\ i_2$ et $b'_2\ c'_2\ d'_2\ e'_2\ f'_2\ g'_2\ h'_2\ i'_2$, en joignant ceux-ci nous aurons notre diagramme entropique dont l'aire correspond à la chaleur transformée en travail, c'est-à-dire en rendement

$$\text{de } \frac{6.680}{17.000} = 0{,}39.$$

(6.680 représente l'aire du diagramme entropique et 17.000 = K A' L M la quantité de chaleur qui serait susceptible d'être transformée en puissance vive.)

Le diagramme tracé donne immédiatement pour un état donné de la vapeur :

La pression p, la température t, l'entropie s, la quantité de chaleur q et le volume v.

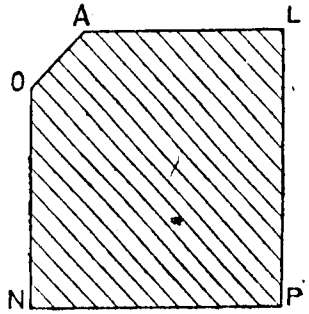
La surface totale N'O A'L P représente la chaleur contenue dans 1 kg. de vapeur à 950 gr. (636 calories), soit à notre échelle 124.516 mm².

Chaleur transformée en puissance vive

$$\frac{6.680 \times 636}{124.516} = 34 \text{ calories } 12.$$

Quantité de chaleur pour 124 ch,01

$$= \frac{124{,}01 \times 75}{425 \times 0{,}75} = 29 \text{ calories } 1$$

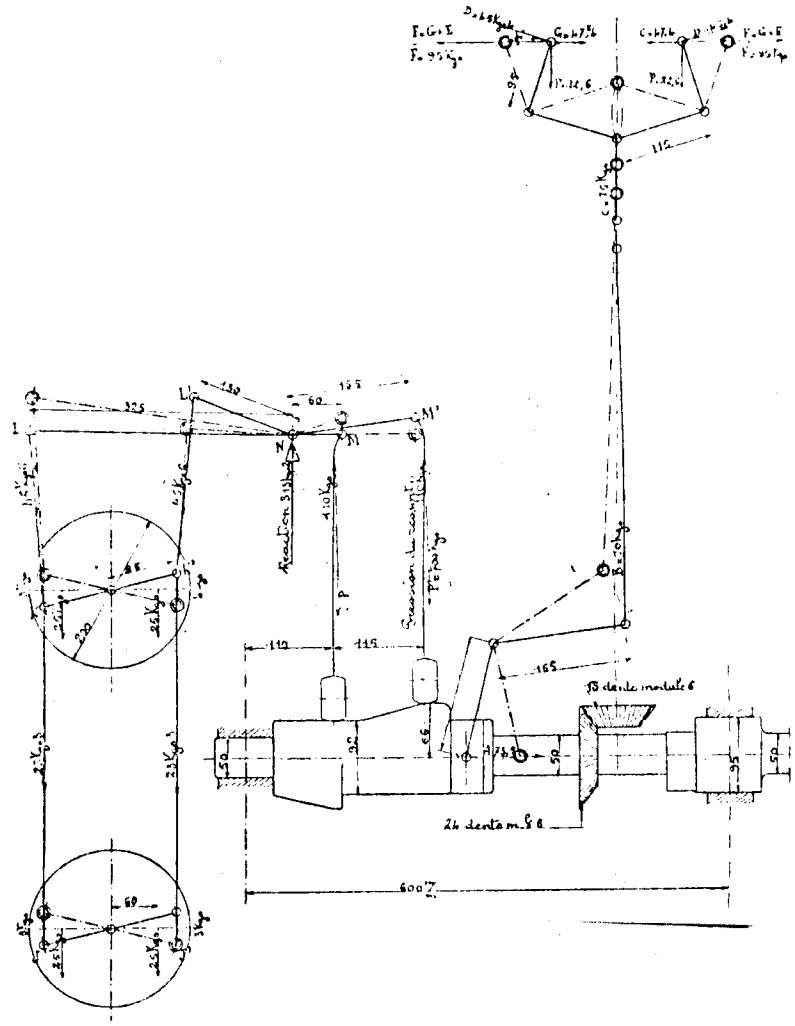


et par heure $29{,}1 \times 3{,}600 = 104{,}760$ calories soit :

$$\frac{104.760}{34{,}12} = 3.070 \text{ kg. de vapeur. Ce nombre de } 3.070 \text{ kg.}$$

correspond, sauf erreurs provenant des tracés graphiques à celui de 3.048 kg. trouvé précédemment, néanmoins pour toute sécurité nous adopterons une consommation horaire de 3.100 kg. à une pression de 950 gr. par cm².

Epure des organes de distribution (fig. 57)



Résultats :

Pression initiale absolue de l'air aspiré	Essais des mines	1 kg,033
Pression finale de l'air comprimé ...	de Dourges	135 kg.
Puissance nécessaire à la compression.....		118 ch,5
Pression initiale absolue de la vapeur.....		0 kg,950
Pression absolue au condenseur.....		0 kg,065
Durée de la pleine admission.....		85/100
Travail effectif de la machine avec rendement mécanique de 0,75.....		124 ch,01
Consommation à la puissance de 124 ch,01...		3.048 kg.
Consommation par cheval heure.....		24 kg,58
Consommation à la puissance de 118 ch,5 ...		2.826 kg,4
Consommation par cheval heure.....		23 kg,94
Consommation moyenne par m³ d'air réellement aspiré à la pression atmosphérique et comprimé à 135 kg. par cm².....		7 kg,76
Puissance absorbée par le compresseur tournant en circuit ouvert (Essais des mines de Dourges) environ.....		55 ch.

Détermination des différents organes de distribution (Fig. 57).

Nous supposons la vapeur à la pression de 1 kilog.

Pression totale intérieure avec un obturateur

$$74 \times (4{,}2 \times 2) \times 1 = 621 \text{ kg,}600$$

Pression compensatrice sur les faces opposées a et *b*

$$= (74 \times 2 \times 0{,}9) + (74 \times 2 \times 2) - \frac{(3{,}14 \times 30^2 \times 11)}{4} = 351 \text{ kg,}45$$

Charge d'un ressort d'application de l'obturateur sur la glace en ajoutant une pression de 30 kg. pour l'étanchéité

$$\frac{(621{,}6 - 351{,}45) + 30}{22} = 13 \text{ kg,}6$$

Effort de glissement H avec graissage intermittent en admettant $f\ 0{,}1 = 3$ kg.

Poids approximatif d'un obturateur 125 kg.

Centre de gravité de l'obturateur

$$= \frac{570 \times 45 + 414 \times 44 + 900 \times 78}{570 + 414 + 900} = 60 \text{ mm.}$$

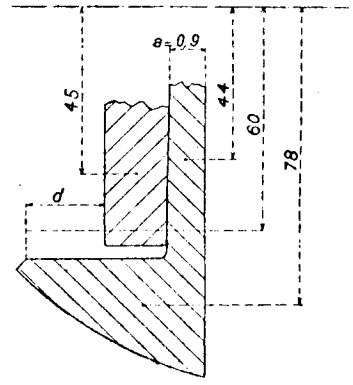
Effort de frottement pour un axe de 46 mm.

$$= \frac{(3 \times 100)}{22{,}5} + \frac{(25 \times 60)}{22{,}5} \times 0{,}1 = 8 \text{ kg.}$$

Effort total au centre de l'arbre de l'obturateur

$$25 \times 60 + 3 \times 100 + 8 \times 22{,}5 = 1.980 \text{ kg.}$$

Effort à chaque maneton des manivelles de commande des obturateurs J et J' $= \frac{1980}{85} = 23$ kg,3.



Effort total aux points K, K' L et L' $= 23{,}3 \times 2 = 46$ kg,6.

Rapport total de la course de l'obturateur à la course de la came $\frac{48}{20} = 2{,}4$.

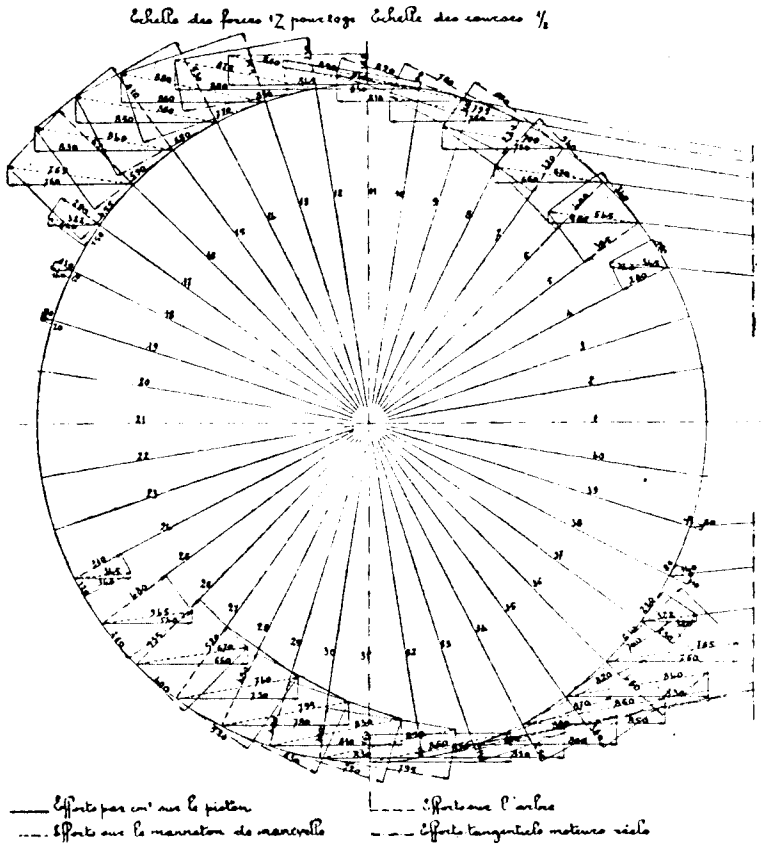
Nous avons donc en J, J' K et K' $\frac{48 \times 85}{100} = 40$ m.m,8.

Rapport de la course du maneton de commande de l'obturateur et de la came $\frac{40{,}8}{20} = 2{,}04$.

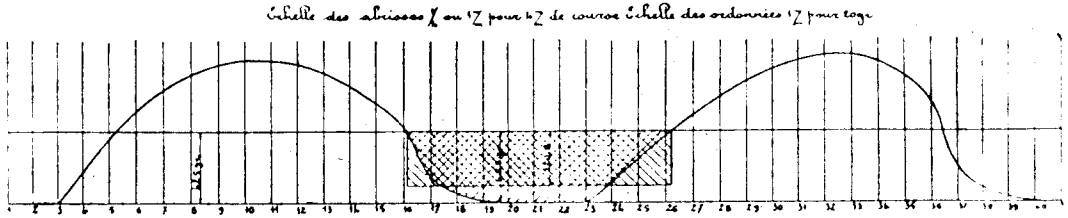
Pression théorique sur le galet en M et M'

$$= 46{,}6 \times 2{,}04 = 95 \text{ kg,}064.$$

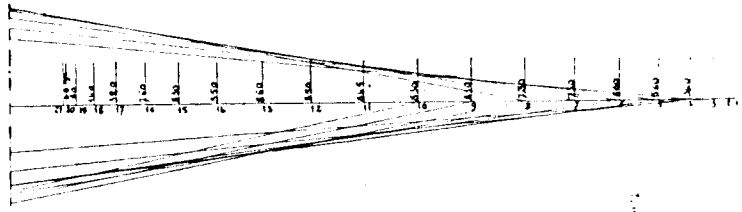
Décomposition des efforts sur les pistons



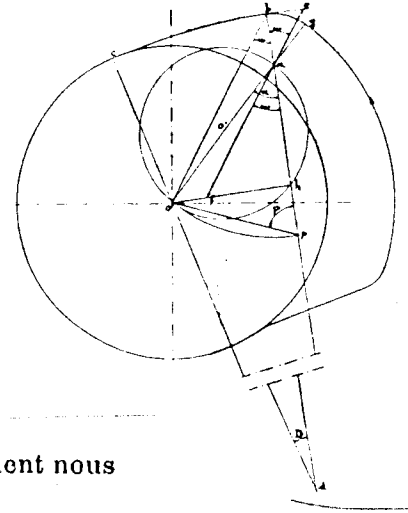
Courbe des efforts tangentiels moteurs réels



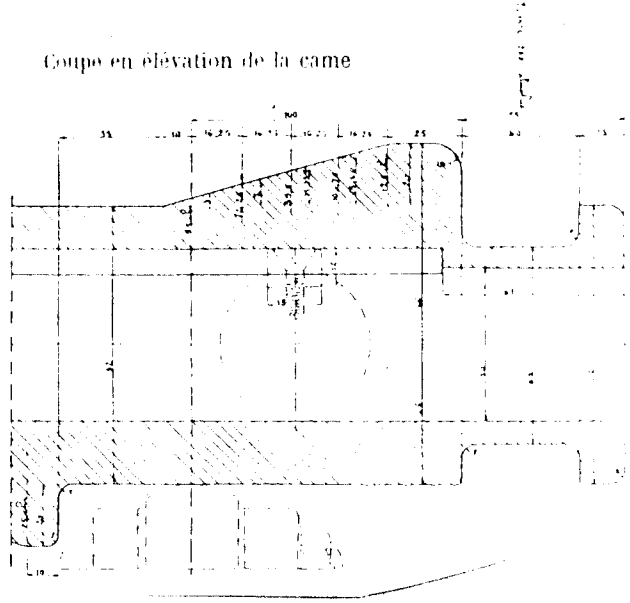
Efforts sur les pistons aux différents points



Détermination de l'accélération du galet (fig. 58)



Coupe en élévation de la came



Pour tenir compte du poids des pièces en mouvement nous prendrons 110 kg.

La levée de la came étant de 20 mm. les longueurs respectives des leviers auront :

$$L, N = 325 \text{ mm.}, N, M = 155 \text{ mm. } L' N = 130$$
$$\text{et } N, M' = 60 \text{ mm.}$$

Pour une pression de 110 kg. la masse sera : $\frac{110}{9,81} = 11,2.$

Vitesse angulaire de la came $\frac{3,1416 \times 160}{30} = 16 \text{ m},74.$

La vitesse maximum W est en b égale à OP $\times$ V (tracé de la came).

Pour déterminer Op, des points o, a et d, traçons les lignes $d\,b$ et $c\,g$ (FIG. 58).

Du centre a avec un rayon $a\,o$ traçons un arc de cercle qui coupe la ligne $d\,b$, le point de rencontre détermine p nous

avons donc dans le triangle $o\,a\,p$

$$c\,p = \frac{o\,a \times sin}{sin\ p} = \frac{0{,}51 \times 707}{924} = 0{,}39$$

Nous obtenons $W = 0{,}39 \times 16{,}74 = 6{,}54$ par seconde.

L'accélération en b est représentée par la ligne $e\,f$.

e point de rencontre de la parallèle à $o\,b$ passant par le centre a et de la courbe de montée de la came.

Pour déterminer le point f nous traçons une circonférence de diamètre $o\,a$, laquelle coupe $d\,b$ en h, traçons $o\,h$, f est le point de rencontre de la parallèle à $o\,b$ passant par le centre a.

Or, d'après notre tracé, nous avons

$a\,b = 15$ mm, $o\,c = 46$ mm., $c\,d = 185$ mm.

$do = dc - oc = 185 - 46 = 139$ m/m.

$dh = d\,o \times cos$, $D = 139 \times 0{,}966 = 134{,}274$.

$a\,h = d\,b = (a\,b + d\,h) = 185 = (134{,}274 + 15) = 25{,}726$.

$$f\,a = \frac{a\,h}{cos,co} = \frac{35{,}726}{0{,}816} = 43{,}8 \text{ et } a\,e = \frac{a\,b}{cos,co} = \frac{15}{0{,}816} = 18{,}36$$

Nous avons pour valeur de l'accélération

$$e\,f = 43{,}8 + 18{,}36 = 62{,}16.$$

Le produit de la masse par l'accélération nous donne l'effort théorique de pression exercé sur la came, soit

$$11{,}2 \times 62{,}16 = 696 \text{ kg } 192.$$

Pour tenir compte de toutes réactions possibles, nous calculerons nos recettes à 700 kg.

Pour ceux-ci nous avons $700 = \dfrac{d^3}{16 \times \frac{D}{2}} \times t$ d'ou d

$$= \frac{16 \times 700 \times 25}{3{,}14 \times 65} = 11 \text{ mm.}$$

Formule dans laquelle d = diamètre du fil.

t = — du ressort.

t = travail du métal sous charge.

Hauteur sous tare = 180 mm.

— — charge = 160 mm.

Déterminons le nombre de kg N que les cames absorbent approximativement :

Nous avons $P = Q \times f$ et f coefficient de frottement $= 0{,}05$

$$\text{Ou } N = P \times v = \frac{(700 \times 2)\,0{,}05 \times 3{,}14 \times 0{,}132 \times 160}{60} = 77 \text{ kg } 4$$

La pression P du ressort en charge, c'est-à-dire dans la position P, est égale à 700 kg.

Nous supposons les deux ressorts en charge pour déterminer l'effort de frottement.

(Cette hypothèse ne sera jamais atteinte attendu que les galets ne peuvent se trouver simultanément dans cette position de travail).

Le coefficient de frottement pour un graissage continu étant de 0,035 à 0,05, nous adoptons le maximum 0,05.

L'effort de réaction au glissement des cames contre les galets sera $(700 \times 2) \times 0{,}05 = 70$ kg.

Effort de glissement des cames sur l'arbre horizontal de commande $70 \times 0{,}05 = 3{,}5$.

Effort en A $= 70 + 3{,}5 = 73$ kg 5. Effort en V

$$= \frac{73{,}5 \times 14{,}5}{165} = 64 \text{ kg } 5$$

Nous prendrons pour plus de sécurité 70 plus le poids du manchon, environ 5, soit 76 kg pour l'effort total de glissement du manchon du régulateur sur l'arbre vertical de commande ;

pour chaque levier en $D = \dfrac{75 \times 115}{2 \times 95}$ 45 kg 4, soit en E

$$= \frac{45{,}4}{cos,\,a} = \frac{45{,}4}{0{,}956} = 47 \text{ kg } 4.$$

L'effort G de chaque ressort intérieur agissant sur les masses du régulateur pour repousser la came est donc de 47 kg. 4.

La force centrifuge des masses du régulateur pour que celui-ci soit en équilibre devra donc vaincre l'effort du ressort, plus l'effort de déplacement de la came d'où :

$$F = G + E = 95 \text{ kg} = \frac{P}{g} \times v^2 \times r = \frac{P}{9{,}81} \times (22{,}5)^2 \times 0{,}0825$$

et P = poids d'une masse $= \dfrac{95 \times 9{,}81}{(22{,}5)^2 \times 0{,}0825} = 22 \text{kg } 6$

g = accélération = 9,81 :

v = vitesse angulaire $= \dfrac{nx\,n}{30} = \dfrac{3{,}1416 \times 213{,}33}{30} = 22{,}5$

r = rayon des masses.

n = nombre de tours.

Le ressort devra avoir un diamètre de

$$\sqrt[3]{\frac{16 \times 47{,}4 \times 25}{3{,}14 \times 45}} = 5 \text{ mm.}$$

Poids maximum du régulateur dont le centre de gravité est distant de 110 mm. environ de son axe de rotation.

Puissance absorbée par celui-ci en kg.

$$P \times v = 70 \times \frac{(0{,}220 \times 3{,}14 \times 213{,}33)}{60} = 171 \text{ kg } 5$$

Lorsque le régulateur travaille il produit un effort de 75 kg qui vient s'ajouter au poids du régulateur et le tout forme la charge portée par le roulement à billes, soit un total de 70 + 75 kg = 145 kg.

Puisssance absorbée par le roulement à billes avec $f = 0{,}006$.

$$(145 \times 0{,}006) \times \frac{3{,}14 \times 0{,}065 \times 213{,}33}{60} = 0 \text{ kg } 475$$

Puissance absorbée par les engrenages de commande.

$$\frac{(70 \times 110}{40} + 145 \times 0{,}006) \times 0{,}05 \times \frac{(3{,}14 \times 0{,}080 \times 213{,}33)}{60}$$

= 8 kgm 66, 40 mm. étant le rayon moyen de l'engrenage.

Effort au diamètre primitif des engrenages $\dfrac{70 \times 110}{40} + 145$

$$\times 0{,}006 + \frac{(70 + 110}{40} + 145 \times 0{,}006) \times 0{,}05) = 203 \text{ kg.}$$

La hauteur moyenne des dents étant de 10 mm. le moment fléchissant sera $203 \times 10 = 2.030$ et $\dfrac{I}{V} = \dfrac{45 \times 8^2}{6} = 480$ d'où

le travail du métal $\dfrac{2030}{480} = 4 \text{ kg } 2$

Pression sur le palier $R = \dfrac{700 \times 490}{600} + \dfrac{700 \times 375}{600} = 891 \text{ kg } 6$

$S = (700 \times 2)\ 891{,}6 = 508 \text{ kg } 4$

Puissance absorbée par le palier R = 891,3 × 0,05

$$\times \frac{(3{,}1416 \times 0{,}05 \times 160)}{60} = 18{,}63$$

Puissance absorbée par le palier S = 508,4 × 0,05

$$\times \frac{3{,}1416 \times 0{,}095 \times 160}{60} = 20{,}23$$

Puissance totale en admettant 1 kg pour la pompe,
77,4 + 18,63 + 171,5 + 0,475 + 8,66 + 20,23 + 1 = 297 kgm 9 soit 3 ch. 972.

D'où un moment de torsion $\dfrac{297{,}9}{\dfrac{3{,}14 \times 0.05 \times 160}{60}} \times 50 = 35.600$

Le moment résistant de l'arbre étant $\dfrac{3{,}14 \times \overline{50}^3}{16} = 24.543$

$$\text{d'où } t = \frac{35600}{34543} = 1 \text{ kg } 5$$

Le travail des organes de la distribution est absolument rationnel.

CONCLUSION

En résumé, par ce qui précède, nous voyons que la commande des compresseurs à basse et haute pression par

action directe d'un cylindre à vapeur construit spécialement pour l'utilisation des basses pressions est pratiquement réalisable.

Les machines à mouvement alternatif peuvent avantageusement être comparées aux turbines utilisant les mêmes vapeurs d'échappement, en tant que puissances moyennes ; par contre ces dernières ne sauraient les remplacer pour les hautes pressions nécessaires à la traction par locomotives à air comprimé, dans ce dernier cas les machines à mouvement alternatif peuvent seules être employées.

Nous aurions voulu pouvoir établir des prix de revient comparatifs entre les frais d'installation de traction à air comprimé par locomotives sans et avec récupération des freinages, de consommation d'une même installation avec les mêmes compresseurs commandés électriquement, à action directe par vapeur vive et vapeur d'échappement, Mais étant donné le peu de stabilité des prix usités actuellement, tant pour les matières premières que pour les salaires de la main-d'œuvre, il ne nous a pas été possible d'arriver à des résultats sérieux.

Dès que nous aurons une situation plus stable et que l'expérience des machines en cours d'exécution auront sanctionné nos prévisions, nous nous empresserons de faire une nouvelle communication.

Valenciennes, le 24 avril 1920.

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

BULLETIN No. 132 JULY, 1922

A STUDY OF COAL MINE HAULAGE IN ILLINOIS

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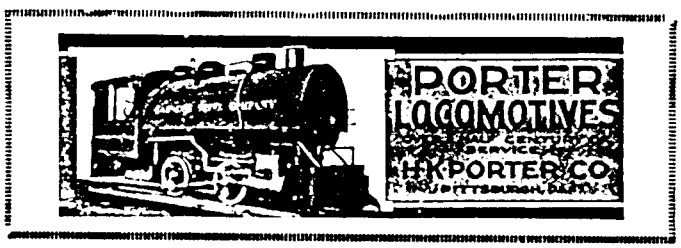
From 1875 to 1895 may be called the experimental period of the compressed-air locomotive. Ten or twelve were built during this twenty-year period and were installed by operators who desired a haulage system that would eliminate fire risk, be free from the dangers of electric wires, and be comparatively safe in a gassy mine. In construction compressed-air locomotives differ from steam engines mainly in having, instead of a steam boiler, a large storage tank which can be charged with air at a pressure of from 600 to 1000 pounds per square inch, and a reducing valve set to supply air to the cylinders at a constant pressure of 150 pounds. From 1895 to 1908 great improvements in design and manufacture were made, and several hundred locomotives were furnished to mining companies.

In 1908 the first two-stage compressed-air locomotive was put upon the market and, in the three years succeeding, over 100 were built.*

According to the H. K. Porter Company of Pittsburgh, Pennsylvania, there were in 1921 no compressed-air locomotives operating in the coal mines of the Mississippi Valley, but in the mines of Western Pennsylvania and West Virginia the total number was about 150.

There are two great advantages of compressed-air locomotives: first, they are comparatively safe for use in gassy mines, and second, they require neither trolley wire nor rail bonding.

On the other hand they are bulky, and their radius of operation is limited by their air-storage capacity. However, in mines having ample cross-section of the entries this is not serious as tanks of a capacity sufficient for a run of several miles may be used.



Gewerbefleiss
December 1922

Translated from the German by Scott Robertson

Compressed Air Locomotives, Old and New

The concept of using atmospheric air in a compressed state as a motive source for locomotives had already emerged by 1870. According to the status of the technology at the time they were built like steam locomotives and equipped with existing cylindrical tanks, in the way they find employment today as fireless locomotives. The tanks provided for the admission of about 6-10 cubic meters (212-353 cubic feet) of compressed air at 12 atmospheres (162 psig), which was reduced before entry of the air into the cylinder by means of a special reducing valve to 4 atmospheres (44 psi). The driving range of such locomotives was naturally very short, so they went gradually to higher pressures, at first up to 30-50 atmospheres (426-720 psi). But riveted tanks were still being used in the case mentioned, although of smaller diameter, and in fact depending on the size of the locomotive, one or two or more in varying sizes were used. The engine cylinders were duplex with a working pressure of 12 atmospheres (162 psi) and cutoff at 30-70% of the piston's stroke. So as to prevent the excessive air-cooling accompanying the pressure drop from 50 to 12 atmospheres (720-162 psi), and since they feared that at the short cutoffs the slide valves and pistons could eventually freeze, the locomotives were equipped with special hot water tanks, through which the air was conveyed on the way to the cylinder's intake pipes. The tanks had to be filled quite often with hot water, which led to disagreeable interruptions. Later, as in the case of the fireless locomotives, steam present in the tank at 12-18 atmospheres (162-250 psi) was injected into the air, whereby a longer reheating of the air was attained.

In this form the compressed air locomotive was used in mining and in switching yards. Later, after smaller diameter tanks for higher pressures, pressed according to the seamless process, could be procured, the locomotives were equipped with a greater number of these tanks and the pressure was increased to 80-100 atmospheres (1161-1455 psi). Reheating of the air cooled off by pressure reduction also took place in the way just shown, in fact they even built a tank with a separate burner within like a small boiler. The cylinders were sometimes duplex; by this time they sometimes were also using compound engines. These also were used with cutoffs from 30-70% of the piston's stroke. The area of application of these locomotives extended only to railways which served the public traffic, for example, street and suburban railways in the larger cities such as Paris and New York. For longer main stretches of railway, however, compressed air locomotives weren't considered, since the more frequent refilling of the air and hot water tanks didn't permit smooth operation; an operation of this kind also became too expensive. In the switching yard and on street and suburban railways the compressed air locomotive also had no long lifespan; it was soon displaced by the introduction of the electric locomotive.

While in America the compressed air locomotive found application in coal mining in greater numbers, it could find next to no introduction in coal mining in Germany for many administrative reasons. Besides the horse, which gradually became unable to meet increasing production, it was cable haulage and electric locomotives, as well as gasoline locomotives, that exclusively ruled the haulage industry. Furthermore, the compressed air locomotive in its design at the time was still relatively imperfect, so that one wouldn't expect a particular advantage from this medium of transport. But the uniqueness of compressed air helped it yet to find its eventual success; completely special, when it was improved and perfected. While electric locomotives with overhead wires soon got themselves into accidents through contact with the drive-wire, the electric locomotives as well as the gasoline locomotives deteriorated the air, especially in the close spaces, which have less contact with wind currents. Eventually it was because of the inevitable formation of sparks by the overhead wire locomotives and the possibility of explosion with the gasoline locomotives that the threat of fire-damp had to be acknowledged as the greatest danger for the miner. Since with the compressed air locomotive these kinds of dangers to the miner are impossible, it serves even in the aforementioned badly-ventilated close stretches because of the improvement of the mine air by the locomotive exhaust. The mining industry immediately recognized this advantage and so finally took the compressed air locomotive for itself, to meet this important demand. Meanwhile, the compressed air locomotive had undergone further improvements, after they had produced the air tank according to the seamless method with stronger walls for higher pressures of over 200 atmospheres (2925 psi), and moreover they had been able to entrain the warm mine air for the reheating of the cooled-off compressed air before intake into the cylinder. They also abandoned the duplex engine and went exclusively toward the compound engine. The reheating of the air with the warm mine air before intake into both the high- and the low-pressure cylinders sufficed perfectly, even for longer trips, with shorter cutoffs, without having to fear freezing-up of the slide valves and pistons.

The firm of A. Borsig, Berlin-Tegel, employed itself for more than 13 years with the building of compressed air locomotives for the coal haulage industry and also for tunnel building. The initially chosen design, with the machinery and power cylinders situated within the chassis, was very soon abandoned because of the inaccessibility and difficulty in seeing. The experience in mining operations gathered up to this point showed that for the extraordinarily rough haulage work, an extremely powerful and substantial locomotive of simple construction was called for, which was well-built in its particular parts and provided overall good accessibility, and so came to be the compressed air locomotive shown in Figure 1. (Editor's note: here is omitted a discussion of the advantages of mining locomotives that have two driver's seats over those that have only one.)

The horse, which earlier served exclusively for the transport of coal underground, and even of late, till the outbreak of the war, found employment in the close stretches for the fetching of the transport cart, was eventually displaced by the so-called feeder locomotive, Figure 3.

With all locomotives the emphasis is placed on solid, powerful design and good construction according to the rules of steam locomotive building. The heavy A. Borsig compressed air locomotives have the great advantage that they don't go into a skid on the unavoidably slippery haulage tracks and they also withstand rough haulage operations far better than lighter-built locomotives. In reference to the cylinder measurements and the controls, the locomotives are so perfected that they guarantee a very trifling air consumption. Test runs undertaken have shown that the air consumption of the Borsig compressed air locomotives, related to the ton-kilometer, amounted to .6-.7 cubic meters.

There are currently about 200 units of varying design of the described compressed air locomotives in the Rheinisch-Westfalischen coal field. The remarkable advantages of the compressed air locomotive have also brought about its further dispersion and so Borsig compressed air locomotives are also in operation in the South German coal field Hausham, and also recently a number of two-driver-seat locomotives were delivered to an obersclesische (?meaning unknown) coal mine.

Modern five-stage compressors serve for the production of the high-tension compressed air of 200 atmospheres (2925 psi), see Figure 4. The high tension compressed air is conveyed by the compressors into an air accumulator, see Figure 5, and from there to the filling station, Figure 6.

Locomotives of considerably larger size are used for tunnelbuilding. Figure 7 shows a two-axle locomotive which serves to advance the broken-out rock to the front part of the tunnel behind the already completed part of the tunnel, from where the carts are brought outdoors by the heavy locomotives, Figure 8.

Gewerbefleiß

Zeitschrift des Vereins zur Beförderung des Gewerbefleißes

Jahrg. 101. Dezember 1922. Heft 12.

Druckluft-Lokomotiven älterer und neuerer Bauart.

Der Gedanke, die atmosphärische Luft in zusammengepreßtem Zustande als Treibmittel für Lokomotiven zu verwenden, tauchte bereits in den 70er Jahren des vorigen Jahrhunderts auf. Nach dem damaligen Stande der Technik wurden die ersten Lokomotiven ähnlich den Dampf-Lokomotiven gebaut und mit gewöhnlichen walzenförmigen Behältern ausgerüstet, wie sie heute bei feuerlosen Lokomotiven Verwendung finden. Die Behälter dienten zur Aufnahme von etwa 6—10 cbm Druckluft von 12 Atm. Ueberdruck, der vor Eintritt der Luft in die Zylinder durch ein besonderes Druckverminderungsventil auf 4 Atm. Ueberdruck verringert wurde. Der Arbeitsbereich derartiger Lokomotiven

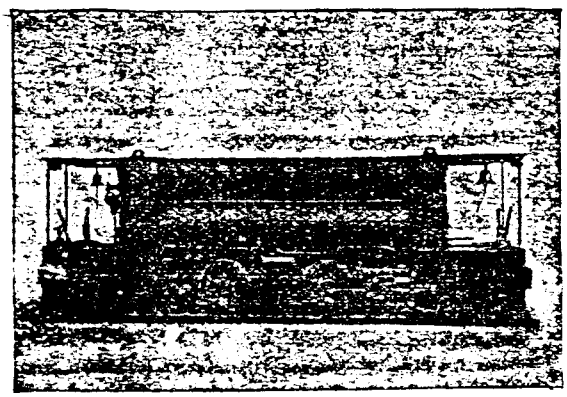


Abb. 1.

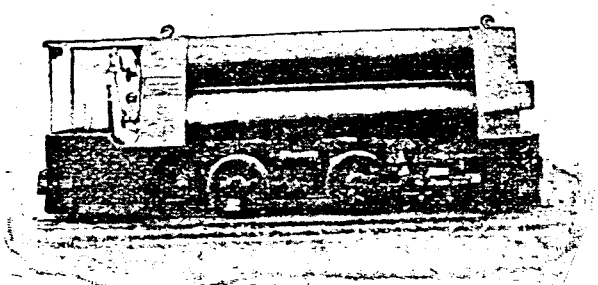
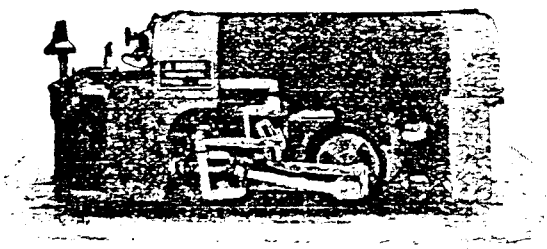


Abb. 2.

war natürlich sehr gering und man ging daher allmählich zu höheren Drücken, bis zunächst 30—50 Atm. Ueberdruck über. Es wurden aber auch hierbei noch genietete Behälter, wie erwähnt verwendet, jedoch von geringeren Durchmessern, und zwar je nach der Größe der Lokomotive einer oder zwei, oder mehrere in verschiedenen Abmessungen. Die Zylinder arbeiteten in Zwillingswirkung mit 12 Atm. Ueberdruck und Füllungen von 70—30 vom Hundert des Kolbenweges. Um einer allzu starken Abkühlung der Luft beim Vermindern des Druckes von 50 auf 12 Atm. Ueberdruck zu begegnen, und da man befürchtete, daß bei den kleinen Zylinderfüllungen schließlich eine Vereisung der Schieber und Kolben eintreten könnte, wurden die Lokomotiven mit besonderen Heißwasserbehältern ausgerüstet, durch die die zu den Zylindern führenden Rohre bzw. die Luft geleitet wurden. Die Behälter

mußten sehr oft mit heißem Wasser aufgefüllt werden, was zu unliebsamen Betriebsstörungen führte. Später wurde, wie bei feuerlosen Lokomotiven, zu dem im Behälter befindlichen Wasser Dampf von 12—18 Atm. Spannung geleitet, wodurch eine längere Wiedererwärmung der Luft erreicht wurde.

In dieser Form ist die Druckluft-Lokomotive für den Bergbau und den Verschiebebetrieb verwendet worden. Später, nachdem Behälter von kleineren Durchmessern für höheren Druck nach dem nahtlosen Verfahren gepreßt, bzw. gezogen werden konnten, wurden die Lokomotiven mit einer größeren Anzahl derartiger Behälter ausgerüstet und auch der Luftdruck bis auf 80—100 Atm. Ueberdruck gesteigert. Die Wiedererwärmung der beim Druckvermindern abgekühlten Luft erfolgte auch bei diesen Lokomotiven in der bereits geschilderten Weise, ja man baute sogar Behälter mit besonderer Feuerung, also kleine Dampfkessel ein. Die Zylinder arbeiteten teils in Zwillingswirkung, zum Teil wendete man auch schon



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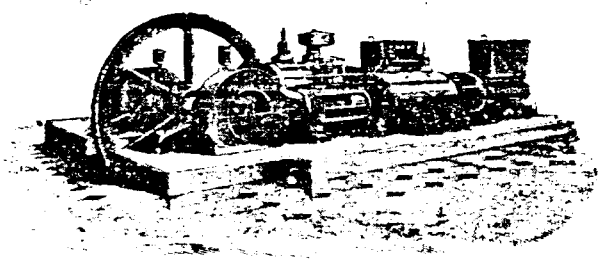

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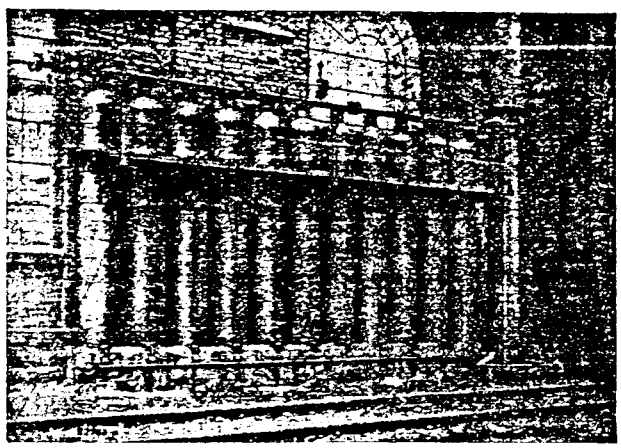


Abb. 5.

die Verbund-Bauart an, wobei ebenfalls mit Füllungen von 70 bis 30 vom Hundert des Kolbenweges gefahren wurde. Das Verwendungsgebiet dieser Lokomotiven erstreckte sich ausschließlich auf Bahnen, die dem öffentlichen Verkehr dienten, zum Beispiel Straßen- und Vorortbahnen größerer Städte, wie Paris und New York. Für längere Hauptbahnstrecken kamen Druckluft-Lokomotiven jedoch nicht in Frage, da das öftere Auffüllen der Luft und der Heißwasserbehälter einen glatten Betrieb nicht ermöglichte und ein derartiger Betrieb auch zu teuer wurde. Auch im Verschiebebetrieb und auf Straßen- und Vorortbahnen hatte die Druckluft-Lokomotive keine lange Lebensdauer; sie wurde sehr bald durch die Einführung der elektrischen Lokomotiven verdrängt.

Während in Amerika die Druckluft-Lokomotive im Kohlenbergbau in großer Anzahl Verwendung fand, konnte sie in Deutschland aus vielen betrieblichen Gründen im Kohlenförderbetrieb zunächst keinen Eingang finden. Neben dem Pferd, das allmählich dem gesteigerten Betriebe nicht mehr entsprach, waren es die Seilförderung, die elektrischen Lokomotiven, sowie die Benzin- und Benzol-Lokomotiven, die ausschließlich den Förderbetrieb beherrschten. Außerdem war die Druckluft-Lokomotive in ihrer damaligen Bauart noch verhältnismäßig unvollkommen, so daß man sich einen besonderen Vorteil von diesem Fördermittel nicht versprach. Aber die Eigenart der Druckluft-Lokomotive verhalf ihr schließlich doch zum Siege, ganz besonders, nachdem sie verbessert und vervollkommnet war. Bei elektrischen Lokomotiven mit Oberleitung stellten sich bald Unfälle durch Berühren des Fahrdrahtes ein; die elektrische Akkumulatoren-Lokomotive sowohl, wie

die Benzin- und Benzol-Lokomotive verschlechterten die Luft besonders in den Nebenstrecken, die vom Wetterstrom weniger berührt werden. Schließlich war durch die unvermeidliche Funkenbildung der Oberleitungslokomotiven, bzw. die Explosionsmöglichkeit der Benzin- und Benzol-Lokomotiven die Schlagwettergefahr als größte Gefahr für den Bergmann nicht von der Hand zu weisen. Bei der Druckluft-Lokomotive sind derartige Gefahren für den Bergmann ausgeschlossen, ja sie

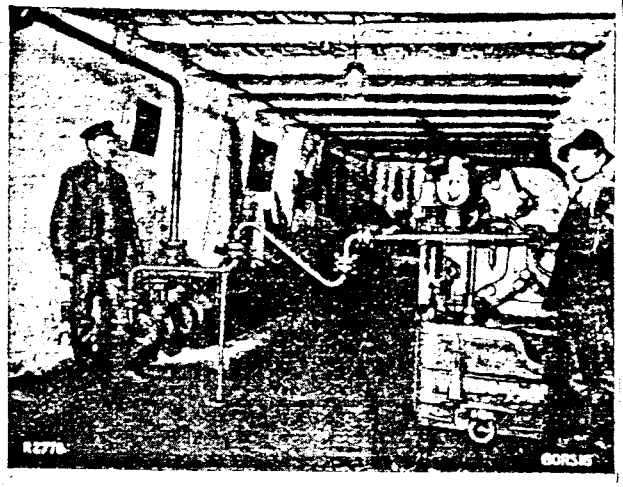
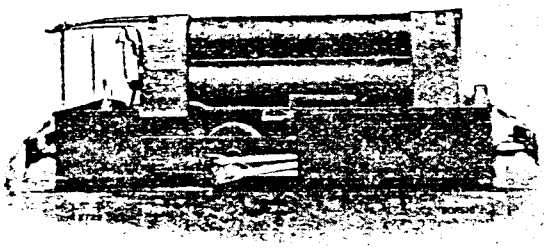


Abb. 6.

dient sogar in den erwähnten schlecht bewetterten Nebenstrecken durch die ausströmende Luft der Verbesserung der Grubenluft. Die Bergbaubetriebe erkannten alsbald die Vorteile und so eroberte sich die Druckluft-Lokomotive schließlich doch dieses wichtige Gebiet. Inzwischen hatte die Druckluft-Lokomotive weitere Verbesserungen erfahren, nachdem man die Luftbehälter nach dem nahtlosen Verfahren mit stärkeren Wandungen für höhere Drücke von über 200 Atm. Ueberdruck herstellen und ferner die warme Grubenluft zur Wiedererwärmung der abgekühlten Druckluft vor dem Eintritt in die Zylinder heranziehen konnte. Man verließ auch die Zwillingszylinder und griff ausschließlich zur Verbund-Zylinder-Anordnung. Die zweifache Wiedererwärmung der Druckluft vor dem Eintritt in den Hoch- bzw. Niederdruck-Zylinder durch die warme Grubenluft genügte vollkommen, selbst bei längeren Fahrten mit kleineren Zylinderfüllungen, ohne eine Vereisung der Schieber und Kolben befürchten zu müssen.

Die Firma A. Borsig, Berlin-Tegel, beschäftigt sich seit mehr als 13 Jahren mit dem Bau von Druckluft-Lokomotiven für den Kohlenforderbetrieb und auch für den Tunnelbau. Die anfangs gewählte Bauart, mit innerhalb des



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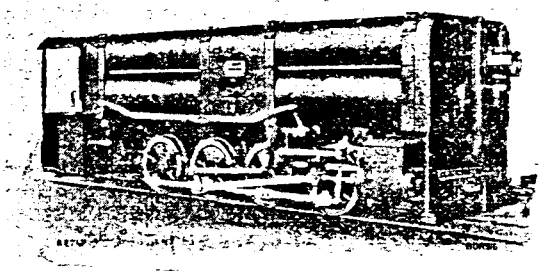

Abb. 8.

Fahrgestelles liegendem Triebwerk und Differenzial-Zylindern wurde sehr bald wegen der Unzugänglichkeit und Unübersichtlichkeit verlassen. Die bis dahin gesammelten Erfahrungen im Bergbaubetriebe ergaben, daß für den außerordentlich rauhen Förderbetrieb eine äußerst kräftige und schwere Lokomotive einfacher Bauart, die in ihren Einzelteilen sorgfältig durchgebildet und überall gut zugänglich ist, in Frage kam, und so entstand die in Abbildung 1 dargestellte Druckluft-Lokomotive. Während bisher alle Druckluft-Lokomotiven nur mit einem Führersitz versehen wurden, hat die Firma Borsig schon die ersten Lokomotiven

mit zwei Führersitzen ausgerüstet, da bei den verhältnismäßig niedrigen und schmalen Profilen der Förderstrecken der Führer nur dann die Strecke einwandfrei überblicken kann, wenn er in der Fahrtrichtung die Lokomotive hinter sich hat und nicht, wie bei der Einführersitz-Lokomotive in der einen Fahrtrichtung die Lokomotive vor sich, so daß er neben der Lokomotive vorbeisehen muß, ein Umstand, der außerdem eine Gefahr für den Führer selbst in sich birgt, insofern, als er sich hierbei Verletzungen zuziehen kann. Die Doppelführersitz-Anordnung ist der Firma Borsig gesetzlich geschützt. Während eine große Anzahl Zechen diesen Vorteil ohne weiteres anerkannte, und sofort zur Anschaffung von Doppelführersitz-Lokomotiven schritt, sind andere Zechen von der ursprünglichen Einführersitz-Lokomotive nicht abgegangen. Die Firma Borsig baut daher auch Einführersitz-Lokomotiven nach Abbildung 2.

Das Pferd, welches früher ausschließlich dem Kohlentransport unter Tage diente, und auch noch in letzter Zeit bis zum Ausbruch des Krieges in den Nebenstrecken zum Herbeischaffen der Förderwagen Verwendung fand, wurde schließlich durch die sogenannte Zubringe-Lokomotive, Abbildung 3 verdrängt.

Bei allen Lokomotiven wird das Hauptgewicht auf solide, kräftige Bauart und gute Konstruktion nach den Regeln des Dampflokomotiv-Baues gelegt. Die schweren Borsig-Druckluft-Lokomotiven haben den großen Vorteil, daß sie auf den unvermeidlich schlüpfrigen Fördergleisen nicht ins Schleudern geraten, und auch sonst dem rauhen Förderbetrieb weit besser widerstehen als leichter gebaute Lokomotiven. In bezug auf die Zylinder-Abmessungen und die Steuerung sind die Lokomotiven so vervollkommnet, daß sie einen sehr geringen Luftverbrauch gewährleisten. Vorgenommene Versuchsfahrten haben ergeben, daß sich der Luftverbrauch, auf den Tonnenkilometer bezogen, bei den Borsig-Druckluft-Lokomotiven auf 0,7—0,6 cbm beziffert.

Von den beschriebenen Druckluft-Lokomotiven sind bis jetzt rund 200 Stück verschiedener Bauart im Rheinisch-Westfälischen Kohlenrevier im Betriebe. Die bemerkenswerten Vorzüge der Druckluft-Lokomotive haben auch eine weitere Verbreitung derselben mit sich gebracht und so sind denn auch Borsig-Druckluft-Lokomotiven im Süddeutschen Kohlenrevier Hausham im Betriebe und neuerdings wurde auch eine Anzahl Doppelführersitz-Lokomotiven an eine oberschlesische Kohlenzeche geliefert.

Zur Herstellung der hochgespannten Druckluft von 200 Atm. dienen besondere fünfstufige moderne Kompressoren, nach der Abbildung 4. Die hochgespannte Druckluft wird durch die Kompressoren in einen Luftspeicher, gemäß der Abbildung 5 geleitet und von dort an die Füllstelle Abbildung 6.

Für den Tunnelbau werden Lokomotiven von erheblich größeren Abmessungen verwendet. Abbildung 7 stellt eine zweiachsige Lokomotive dar, die dazu dient, den Ausbruch beim Vortrieb des Tunnels nach dem bereits ausgebauten Tunnelteil zu befördern, von wo aus die Wagen mit den schweren Lokomotiven nach Abbildung 8 ins Freie gebracht werden.

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COMPRESSED AIR LOCOMOTIVES

DEVELOPMENT — TYPES — WORKING PROCESS — WORKING PRESSURE — DESIGN
AIR CONSUMPTION — TUNNEL LOCOMOTIVES

by Dipl. Ing. **Schulte**, Essen-on-the-Ruhr.

THE reasons for the ever increasing application of compressed air locomotives are more particularly the reliability of operation, simplicity, freedom of movement, independence of temperature differences, the possibility of application in fire damp mines, low construction, permitting of travelling underground in very low and narrow drives, and the extreme simplicity of operation. As compared with the electric locomotive, it has the advantage of being independent of the overhead trolley, and as distinct from the petrol locomotive, it does not vititate the air underground, but on the contrary, improves it. The disadvantage of the compressed air locomotive is that it requires a separate air compressor plant and an extensive pipe system, and also that it must be recharged from time to time.

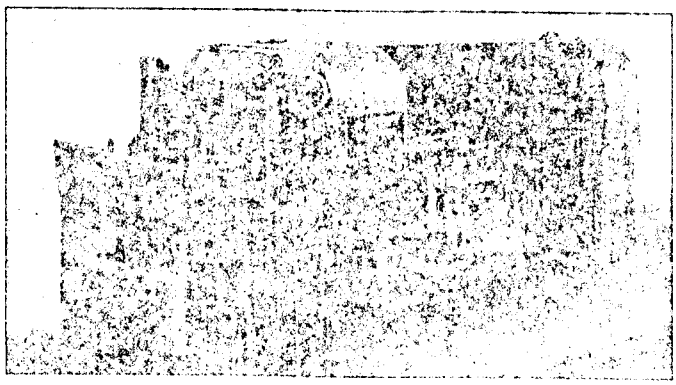


Fig. 1. Mining Locomotive with one air tank.

DEVELOPMENT.

As the application of compressed air locomotives increased, the design has been perfected. The latter improvements had for their object, first of all, the extension of the range of the locomotive, the reduction of the maintenance cost, and the strengthening of the construction. The range of the older type of compressed air locomotive was so small that the machines had to be recharged at the beginning and at the end of each trip. The locomotive had to be charged before it started on its journey with the empty trucks, and had to be charged again before it could return with the laden ones. This meant that the compressed air piping had to be installed right up to the end of the drive. The next object of the designers therefore had to be to increase the range of the machine to such an extent that one charge before each trip was sufficient, so that the air piping had only to be installed in the shaft down to each level. This has been accomplished by increasing the charging pressure. When compressed air locomotives were first being used (1894) the charging pressure amounted only to 30 atms. In 1909 this pressure was increased to 60 atms., one year later to 100 atms., and soon even to 150 atms.; to-day the charging pressure used is even as high as 200 atms. As compared with a pressure of 100 atms. the storage capacity and also the range of the locomotive have thereby been increased by $\frac{100\ (201\ -\ 17)}{101\ -\ 17} = 219\%$ at a working pressure of

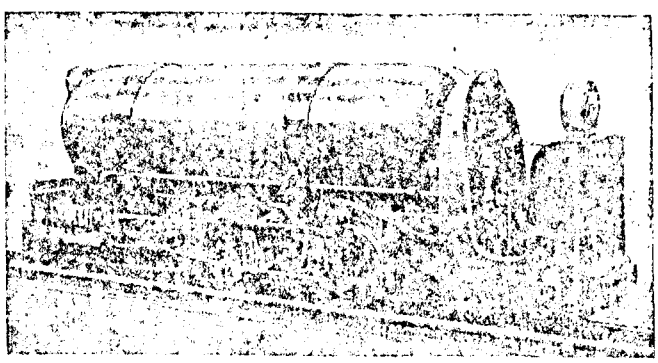


Fig. 2. Tributary locomotive with two air tanks.

16 atms. above atmospheric pressure. Also the capacity of the compressed air tanks on the locomotives has been somewhat enlarged, so that by the two measures combined, the range has been increased to about 2.3 times that of the 100 atms. loco. In actual practice the gain is even larger, because as a rule the full charging pressure is never attained and the pressure difference is comparatively greater at a low pressure than with the higher one. The charging pressure of 100 atms. was about sufficient for a range of twice 3 = 6 kms. with 35 trucks (empty going and full returning), but without switching or shunting operations. If switching was required, the locomotive had to be charged again. Although the work expended for increasing the storage capacity is lost, this is of no consequence considering the advantages obtained by the higher storage capacity.

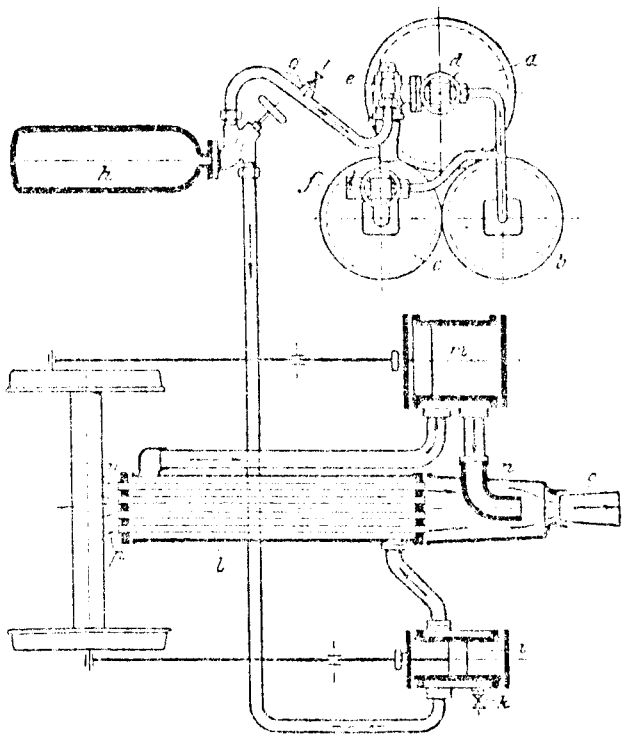


Fig. 3. Working process of a compound compressed air locomotive with intermediate heating.

a, b, c Main air tank. *d* Main throttle valve. *e* Automatic pressure reducing valve. *f* Charging valve. *g* Safety valve. *h* Working tank. *i* High pressure cylinder. *k* Safety valve. *l* Preheater. *m* Low pressure cylinder. *n* Exhaust arrangement. *o* Exhaust. *p* Warm mining air drawn in.

With a charging pressure of 200 atms. this extra expenditure of power as compared with a charging pressure of 100 atms. only amounts to abt. 15 per cent. At the same working pressure of 16 atms. the losses through throttling with the 100 atms.-loco amount to 21.3 per cent. and with the 200 atms.-loco to abt. 29.4 per cent. These figures show that notwithstanding the stronger throttling, by far the greater portion of the working capacity stored up in the air, is converted into mechanical energy.

TYPES OF DESIGN.

The following works are among the formost representatives for the construction of compressed air locomotives: Berliner Maschinenbau A.G. vorm. L. Schwartzkopff; A. Borsig, Berlin; Deutsche Maschinenfabrik A.G. Werk Mülheim; Maschinenfabrik Thyssen & Co. A.G. Mülheim-on-the-Ruhr; Maschinenfabrik Schwarz & Dyckerhoff, Mülheim-on-the-Ruhr. Following are the principal dimensions of the compressed air locomotives manufactured by these firms.

Maximum length between buffers	mm	4000	to	4840
Maximum width	„	950	„	1060
Height above upper edge of rail according to number and dimensions of the compressed air tanks	„	1520	„	1610
Wheel base	„	950	„	1000
Diameter of high-pressure cylinder	„	120	„	125
Diameter of low-pressure cylinder	„	240	„	250
Stroke	„			250
	„	500	„	560
Normal output	HP	15	„	20
Maximum output	„	30	„	35
Drawbar pull measured at the hook of the locomotive	kg	850	„	950
Maximum speed	m/s	4	„	6

Besides these standard locomotives, the majority of works also build smaller machines for the tributary service.

The weight of the locomotives varies considerable with the type. Most locomotive factories employ structural steel frames, the walls of which are naturally lighter and thinner than those of the cast iron frames, exclusively used by Messrs. Borsig. The standard locomotive of Borsig is constructed with two driver's seats, one at either end of the machine, whereas all the other locomotives only have one driver's seat. For this reason the service weight of the Borsig-Locomotive amounts to abt. 9.2 tons wheras the weight of those of the other works fluctuates between 6.5 and 8.6 tons. A heavy weight of the locomotive calls for heavy rails and sleepers, but assures positive starting of the machine. With the riveted structural steel frames of the older types of locomotives the riveted joints became loose, which apart from other disadvantages, affected the working of the control gear. The latest structural steel frames are no longer riveted but are made in one piece. Although they have the advantage of lower weight, the cast-iron Borsig-frame has also given excellent satisfaction in mining work. No breakages have have taken place nothwithstanding the frequent and inavoidable collisions. The cast iron frame has the advantage that it can neither bend nor warp. For this reason the control gear will always work perfectly. The Borsig-locomotive with its two driver's seats affords the driver a clear field of vision in both directions, but this arrangement increases the over-all length of the machine, which is 700 to 800 mm longer than the locomotives designed by the other firms. The arrangement of having the driver's seat at one end as made by the other firms has so far not proved a disadvantage. The line, it is, true, cannot be overlooked quite so well as if there is a seat at either end, but the vistâ may be said to be adequate. At is advisable to put a cover over the driver's seat as a protection against falling rock. The arrangement formerly adopted by Rud. Meyer, Mülheim on the Ruhr (now Deutsche Maschinenfabrik A.-G.) with a look-out hole between the tanks has been abandoned again as, owing to the strong draught more especially against the current of ventilation, this was rather a disadvantage. With the latest patterns the driver's cabin is only made of heavy cast-iron walls. It serves, at the same time, for clearing the

track and as a protection for the cylinders. The lighter constructions of sheet iron have not proved satisfactory, owing to the frequent collisions.

Most factories employ link motion control for reasons

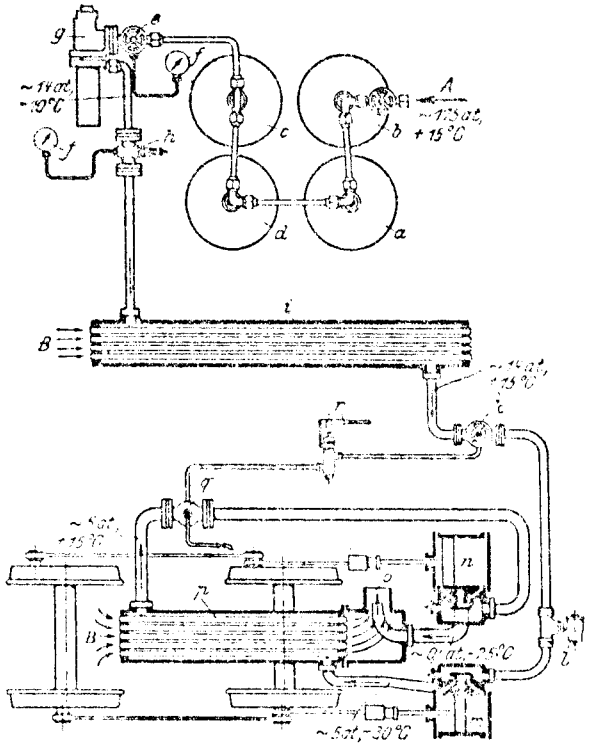


Fig. 4. Working process of a compound compressed air locomotive with preliminary and intermediate heating.

a, b, c, d Main air tank. *e* Main throttle valve. *f* Pressure gauge. *g* Pressure reducing valve. *h* Safety valve. *i* Working tank, preheater. *k* Running valve. *l* Air suction valve. *m* High pressure cylinder. *n* Low pressure cylinder. *o* Induction pipe. *p* Intermediate heater. *q* Automatic change-over valve. *r* Starting valve.

of simplicity and cheapness. The Maschinenbau A.-G. vorm. L. Schwartzkopff, which formerly employed the Heusinger valve gear has now also adopted the link motion gear. The link motion comes up to the requirements of mining service in respect of simplicity but it is liable to failures because it cannot follow the movement of the locomotive springs as readily as could be desired. The Heusinger control has given good satisfaction for mining work, notwithstanding the more complicated construction. The control gear and cylinders are invariably placed on the outside owing to better accessibility and lubrication. Interior control arrangements although they are better protected, have not been as satisfactory.

WORING PROCESS.

The number of storage tanks is between 1 and 4. The Maschinenfabrik Thyssen & Co. builds one single tank with 1480 liters capacity, as shown in fig. 1. A. Borsig makes standard locomotives with four tanks, and tributary locomotives with two tanks (fig. 2). The other factories supply their locomotives as they are ordered with either three or four tanks. The tanks are made of open-hearth steel by the seamless process and are closed at one end. Welded tanks are no longer admissible according to the police regulation regarding the traffic with liquefied gases of the 2nd December 1914. Particular care has been devoted to the thorough drainage of the tanks because the water contained in humid compressed air is liable to rust the interior of the tanks. As a protection against rust the interior of the tanks should be coated with asphalt or other rustproof material.

All factories take advantage of intermediate heating. A. Borsig and Thyssen & Co. moreover employ preheating. The working process in a compound compressed air locomotive with intermediate heating is shown in fig. 3. From the compressed air tanks of the locomotive the compressed air passes through the main throttle valve into the automatic pressure reducing valve under a pressure of 150 atm. where the pressure is reduced to 16- 17 atms. Thence the air enters the working receptacle which forms a receiver. A safety valve is inserted between the latter and the pressure reducing valve. From this receiver the air passes through the operating valve into the high pressure cylinder and from there, after having performed its work, into the intermediate heater. This consists of a tank with a nest of tubes through which the hot mining air is drawn, while the cold air, coming from the high pressure cylinder, passes over the outside of the tubes and is heated by the process from the intermediate heater. The air flows into the low pressure cylinder and from there into the open. The exhaust pipe, at the same time, serves as induction pipe for drawing the mining air into the intermediate heater. Fig. 4 shows the working process of a compound compressed air locomotive with preliminary and intermediate heater (A. Borsig and Thyssen & Co.). In this case the preliminary heater is inserted as working receptacle or

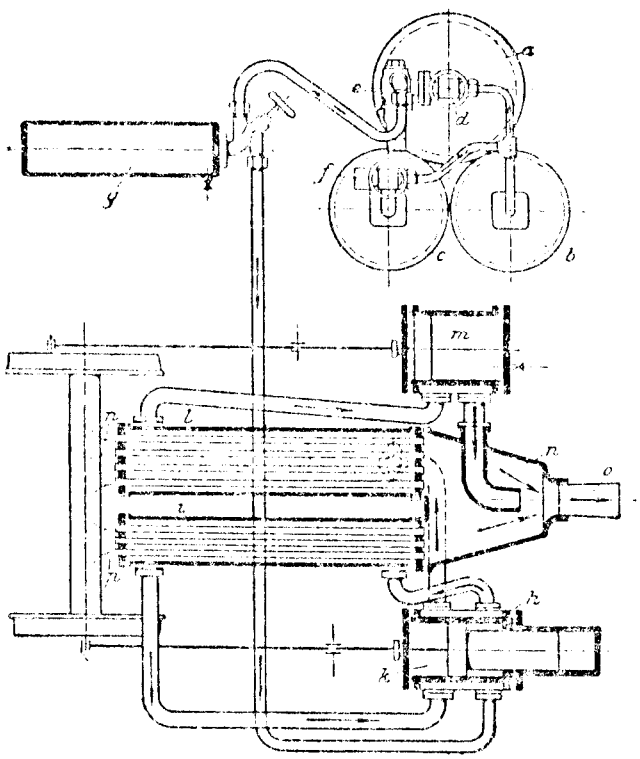


Fig. 5. Working process of a triple expansion compressed air locomotive with double intermediate heating.

a, b, c Main air tanks. *d* Main throttle valve. *e* Automatic pressure reducing valve. *f* Charging valve. *g* Working tank. *h* High pressure stage. *i* Preheater 1. *k* Intermediate stage. *l* Preheater 2. *m* Low pressure stage, double acting. *n* Exhaust arrangement. *o* Exhaust. *p* Hot mining air drawn-in.

receiver between the safety valve in the operating valve. It consists likewise of a receptacle with a nest of tubes through which the warm mining air passes, while the cold working air flows over the outside of the tubes thus

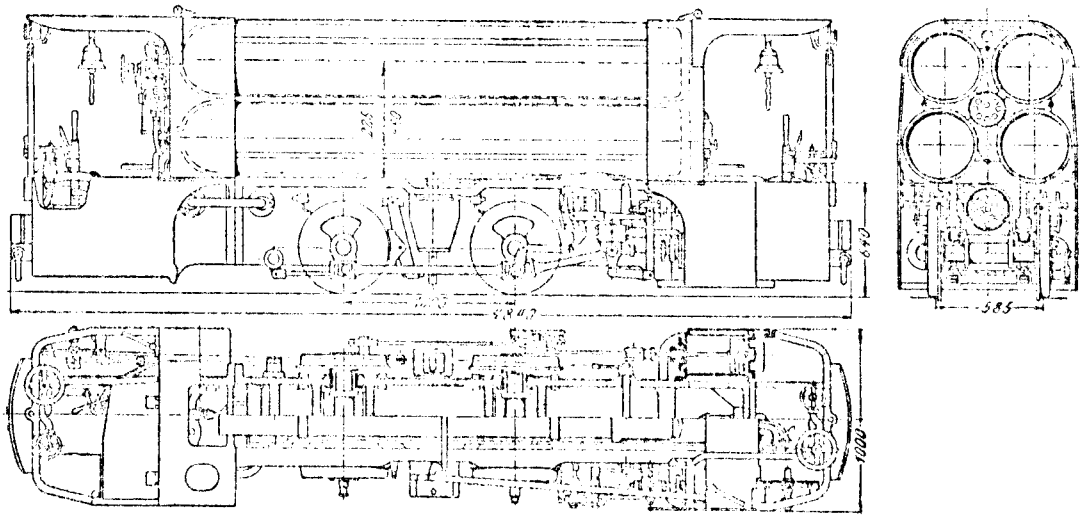
being heated. The drawing also shows the temperatures obtaining during operation. The compressed air in being throttled down from 175 to 40 atms. is cooled from + 15° to — 10° C. i. e. by 25°. In the preheater the original temperature of + 15° is reestablished whereby the working capacity of the compressed air is increased. In the high pressure cylinder the air is cooled from + 15° down to — 30° which is again neutralised in the intermediate heater so that the air reaches the low pressure cylinder also with a temperature of + 15°. In the low pressure cylinder there is a temperature drop from + 15° down to — 25°.

The Berliner Maschinenbau A.-G. build besides compound locomotives also triple expansion locomotives with double intermediate heating. The working process of these machines is illustrated in fig. 5. From the working receptacle the compressed air passes into the high pressure cylinder which is provided with a stepped piston. The piston is guided in a protecting bushing.

WORKING PRESSURE. TYPES.

The working pressure of nearly all modern locomotives is between 12 and 18 atms. With the triple expansion engine it amounts to 25—30 atms. After leaving the high pressure cylinders the air has a pressure of abt. 4 to 5 atms.; with triple expansion engines the pressure between the first and second stage is 9.5, between the second and third stage 3 atms. With the older types the preheater is located in the intermediate heater so that the exhaust of the low pressure cylinder draws the air simultaneously through both. This arrangement has not given satisfaction, because the preheater cannot be securely fastened and is apt to jerk loose.

In figs. 6 to 8 a locomotive is shown in side-elevation, plan view, and section. As may be seen the locomotives have two coupled driving axles. Fig. 9 shows a section through a triple expansion engine built by Schwartzkopff. The Schwartzkopff locomotives have a sanding arrangement of special construction



Figs. 6 to 8. Mining locomotive with double driver's seat.

With this arrangement the intermediate heater must be made in two parts. After having expended its working energy the compressed air flows from the high pressure side of the piston into the preheater 1, from there to the low pressure side of the piston, thence to the preheater 2, and finally to the low pressure cylinder. Both preheaters are connected to the exhaust of the low pressure cylinder by a common bonnet, through which in the same manner as described above, the hot mining air is drawn through both preheaters. The working receptacle, preheater, and intermediate heater are supported in a protected position inside the locomotive frame and must be securely fastened in order not to become loose during operation. The percentage of heating in the preliminary and intermediate heater naturally depends upon the temperature of the air in the mine, which again depends upon the level. Besides increasing the working capacity, the advantage of preliminary heating consists in preventing the cylinder, valve chest, and pipelines freezing. By the application of triple expansion of the air the simplicity of the machine is impaired and the number of pipelines and pipe connections is increased but the working capacity is enhanced and the consumption of air is reduced.

which also permits of using damp sand. These sanding arrangements have given very good satisfaction in practical operation. All locomotives are provided with a starting valve enabling the engine being started at unfavourable positions of the cranks by admitting compressed air direct from the working vessel into the low pressure cylinder. This greatly facilitates starting. All valves and levers are operated from the driver's seat, namely the main stop valve, the control valve, the brake-lever, and valve lever; three pressure gauges are provided in front of the driver for reading the pressure in the tanks, in the working receptacle, and in the intermediate heater. Finally the pressure reducing valve is also placed in a convenient position on the driver's platform.

At first armoured [illegible] hose was used for filling the tanks and later copper piping. Owing to the the scarcity of copper during the war, an attempt was made with steel screw tubes which have given good satisfaction, but after a while they become hard and must be replaced.

The simplicity of the compressed air locomotive permits of its operation by unskilled men. However, it is not advisable to employ very young men as drivers,

because experience proved that lack of responsibility and care reduced the life of the locomotive considerably and increased the repair bill. It was also found that youthful drivers owing to negligence frequently ran without expansion thereby increasing the air consumption very much.

The number of trucks which may be shifted by one locomotive is, as a rule, 35 of a gross weight of abt. 35 tons. The net load with each truck holding 6 tons therefore amounts to $3.5 \times 6 = 21$ tons. With this load it is possible to overcome a gradient of 1:300 with perfect ease. On a level track the load to be carried is greater and may be assumed at abt. 30 tons.

COMPRESSED AIR CONSUMPTION.

The air consumption of the locomotives has been reduced materially by the improvements mentioned according to the publications in "Glückauf" 1912, number 12. It amounted for locomotives without intermediate heating to roughly 1600 to 1700 litres per ton and per km. and referred to the useful weight actually shifted to 3000 till 3200 litres/tons—km. For locomotives with intermediate heating the air consumption was roughly 1000 to 1100 and 2000 to 2100 lt./t.—km. The figures guaranteed by the factories to-day are 700—1400 and 1400—2500 lt./—km. According to tests made by the steam boiler supervision society of collieries in the Essen district in connection with locomotives of the Concordia colliery, Oberhausen, on the 14th of February 1915, the air consumption amounted to 739—895 and referred to actual tonnage 1603—1933 lts./t. km. The line over which the tests were made was 1260 m. long, the average gradient 1:245. The number of trucks amounted to 35. During the up-gradient 30 trucks were empty and 3 were loaded with rock. During the down-gradient run all 35 trucks were filled with coal. During these experiments one charge was sufficient for 3 trips backward and forward, i. e. for a distance of $6 \times 1260 = 7560$ m. The driving range for the latest locomotives with 200 atms. charging pressure is given with 10 km. In reality it is slightly less because, besides hauling the trains on the line, the locomotives have to do a certain amount of shunting work. Besides the condition of the track and the trucks, the number and radii of the curves, the number of the rock trucks to be moved up gradient, and the lengths and gradients of the line are of considerable influence upon the air consumption. Long haulage distances are favourable and short ones unfavourable. The filling of the tanks takes abt. 2 minutes and in addition there is time for connecting and disconnecting the charging tubes so that on the whole the charging time may be taken at abt. 4 minutes.

TUNNEL LOCOMOTIVES.

Besides for mining work compressed air locomotives are also used in the construction of tunnels. The design of these locomotives differs from that of the mining locomotives in accordance with the haulage capacity required. The preliminary and intermediate heating of the working air is not effected by the outside air which is naturally much colder than the air in mines but by small furnaces, built into the preliminary and intermediate heaters. This design would not be practicable with mining locomotives as it would nullify an important advantage of a compressed air locomotive, namely

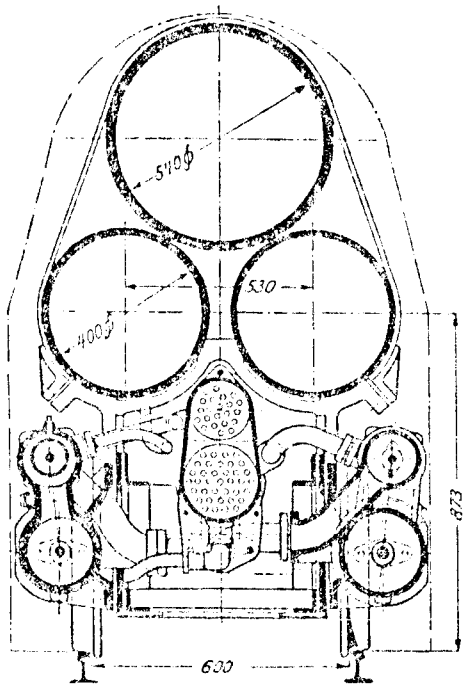


Fig. 9. Triple expansion compressed air locomotive.

its suitability for firedamp mines. In comparing compressed air locomotives with other locomotives from an economic point of view it must be taken into consideration that in many cases other haulage systems are out of the question, owing to the danger of explosion, and also that the cost of coal expended in the production of compressed air are very moderate compared with the other cost of the operation such as wages, depreciation, and capital interest, spare parts, repairs, waste and lubricants. For this reason the compressed air locomotives will continue to be a success for competitor of the other types and their field of application will be widened to an ever greater extent.

Essais théoriques et pratiques d'une locomotive de mine à air comprimé

par M. Paul MARIÈS,
Ingénieur des arts et manufactures.

Dans le numéro du 15 août 1922 de cette revue, nous avons défini un programme de traction par l'air comprimé dans une mine et décrit le compresseur à haute pression calculé pour les données de ce programme.

Examinons maitenant la locomotive correspondante (Fig. 1). Elle a été prévue pour remorquer en palier à 14 km. à l'heure, un train de quarante berlines sur voie de 60 cm., avec un rayon d'action de 6 à 7 km.

L'ensemble de la locomotive (Fig 2) est constitué par quatre parties principales :

1° Le châssis ;
2° Les organes moteurs ;
3° Les réservoirs et réchauffeurs ;
4° La robinetterie.

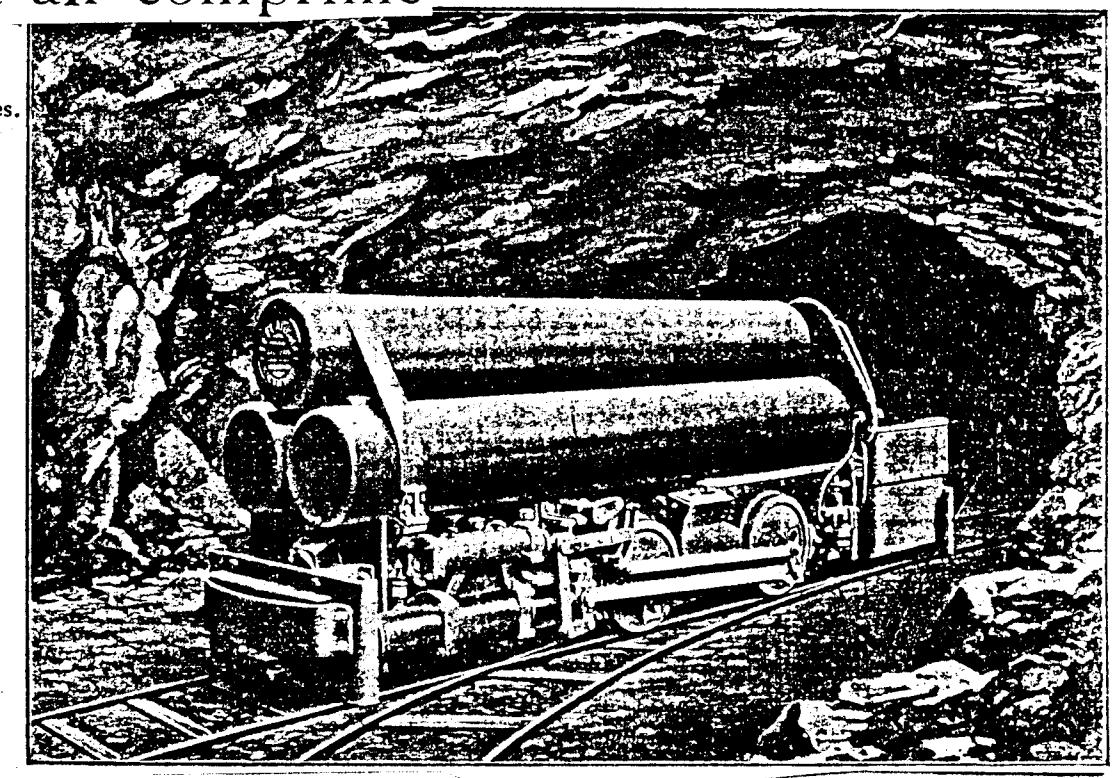


Fig. 1

1° Chassis

Le châssis est formé de deux longerons en tôle, de 20 mm. d'épaisseur, entretoisés à l'avant par une tôle de 29 mm. et entre les essieux par trois tôles de 10 mm. Le kiosque du conducteur placé à l'arrière s'assemble aux longerons par des cornières verticales. Des crochets d'attelage sont prévus à l'avant et à l'arrière. Les longerons sont découpés pour recevoir deux essieux de 1 mètre d'empattement ; ils reposent sur l'extrémité des ressorts à lames bridés sur les boîtes à huile des essieux. Entre ceux-ci et à l'extérieur des longerons, sont logées les sablières dont le remplissage se fait latéralement et dont la commande est ramenée par brimbales au kiosque du conducteur. Il en est de même de la commande des sabots de frein. Entre le premier essieu et l'avant sont disposés les cylindres moteurs fixés horizontalement aux longerons et à l'extérieur de ceux-ci.

Les roues ont 500 mm. de diamètre. Elles sont emmanchées à la presse et clavetées, le corps est en acier moulé et le bandage en acier laminé sans soudure.

2° Organes-moteurs

Ces organes sont constitués par deux cylindres différentiels jumelés travaillant à simple effet pour chaque phase. Ils sont orientés le grand cylindre vers l'arrière et

LOCOMOTIVE A AIR COMPRIMÉ A DOUBLE EXPANSION

Type à cylindres différentiels horizontaux jumelés à simple effet, pour voie de 0 m. 60.

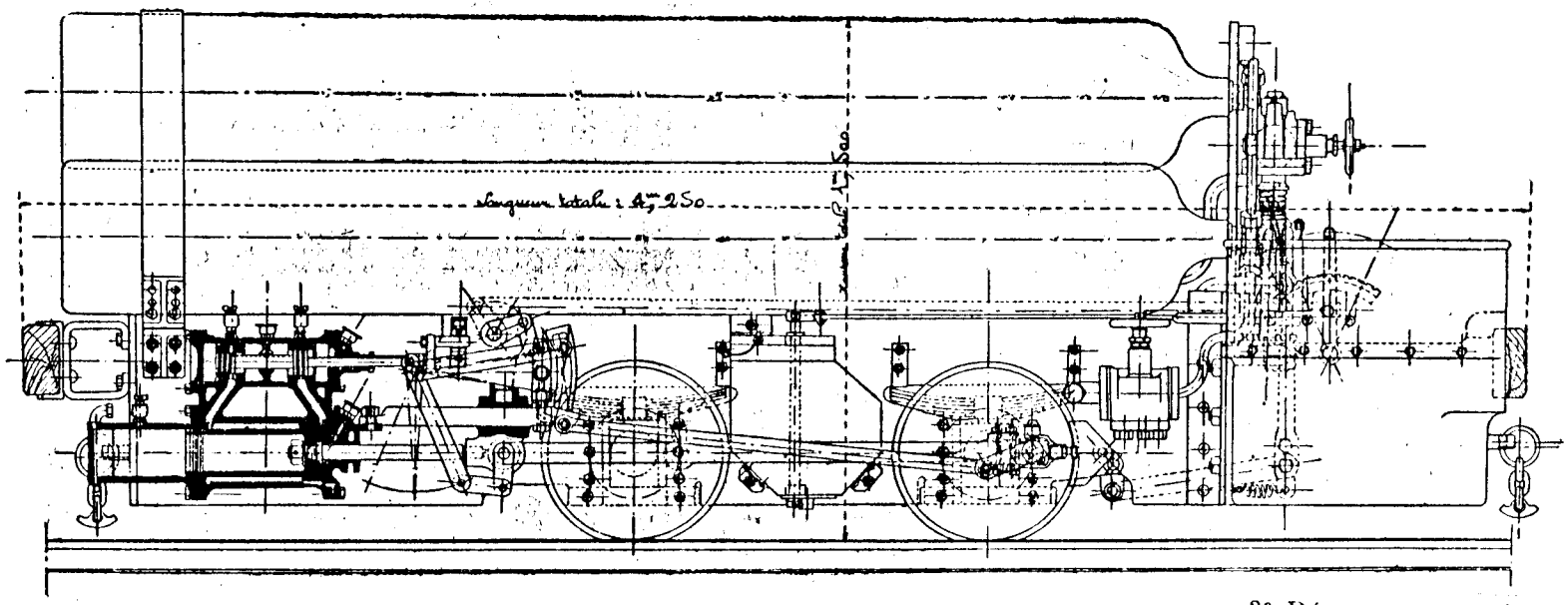


FIG. 2.

CARACTÉRISTIQUES

Alésage	165 m/m	135 m/m
Course	260 m/m.	
Diamètre des roues	500 m/m.	
Empattement	1.000 m/m.	
Pression aux bouteilles	150 kg.	

Pression d'admission	16 kg.
Volume des trois réservoirs	960 l.
Effort de traction au crochet	800 kg.
Vitesse maximum	14 km.
Poids de la locomotive	6.500 kg.
Rayon d'action	6 à 7 k m.

fixés sur les longerons et à l'extérieur, entre la traverse tampon avant et le premier essieu. Ils ont les caractéristiques suivantes :

Alésage	165 mm.	135 mm.
Course	260 mm.	
Pression d'admission minima	10 kg.	

Les pistons différentiels sont à tige passante avec garnitures et crosse à glissière extérieure rapportée.

L'essieu arrière est moteur. Un maneton fixé au corps des roues arrière reçoit le mouvement de bielles motrices et le transmet à l'essieu avant par bielles d'accouplement.

La distribution se fait par des tiroirs cylindriques équilibrés et coulisse du type Walschaerts. La commande du changement de marche se fait du kiosque de manœuvre au moyen d'un levier se déplaçant le long d'un secteur à encoches auxquelles correspondent des valeurs différentes de l'introduction.

3° RÉSERVOIRS ET RÉCHAUFFEURS

Trois réservoirs d'alimentation d'une contenance totale de 960 litres, timbrés à 150 kg., sont placés en triangle au-dessus du châssis et le couvrent sur toute sa longeur (FIG. 3). Un réservoir de travail d'une contenance de 20 litres et timbré à 25 kg. est placé entre les longerons à l'avant du premier essieu et à son niveau.

Un premier réchauffeur est prévu entre le détendeur des réservoirs d'alimentation et le réservoir de travail, et un deuxième réchauffeur entre les cylindres haute et basse pression.

Ces réchauffeurs sont tubulaires et agissent par circulation de l'air chaud ambiant. Le premier est placé au-dessus des deux essieux entre les longerons, le second est intercalé entre le premier réchauffeur et le réservoir de travail. Ils tiennent toute la longueur du châssis.

4° Robinetterie

Ces organes sont fixés sur une plaque de 25 mm. placée à l'arrière de la machine, portant le kiosque de manœuvre à sa partie inférieure et servant de centrage et de fixation aux trois réservoirs d'alimentation.

Ils comprennent :

Une soupape de chargement avec volant de manœuvre placée à l'arrière et à l'extérieur sur le longeron côté gauche, et reliée par manchettes de raccordement au réservoir inférieur gauche.

Des manchettes de raccordement d'équerre assurent ensuite la liaison entre les différents réservoirs.

Une soupape de prise d'air reliée au réservoir inférieur droit avec volant de manœuvre et accolée à un détendeur automatique de 150 k. à 25 k., l'ensemble étant muni d'une soupape de sûreté.

Un manodétendeur du régulateur d'admission intercalé entre le réservoir de travail et les boîtes de distribution des cylindres et portant un levier permettant de faire varier la pression à volonté.

Un clapet de démarrage pour l'envoi directe de la pression aux cylindres BP en cas de départ aux points morts HP.

Deux manomètres à 150 et 25 kg. complètent l'installation.

Cette première locomotive fut d'abord essayée au point fixe.

La figure 4 montre l'installation de la locomotive sur la plate-forme d'essais.

La locomotive repose par ses roues sur quatre galets clavetés sur leurs arbres et

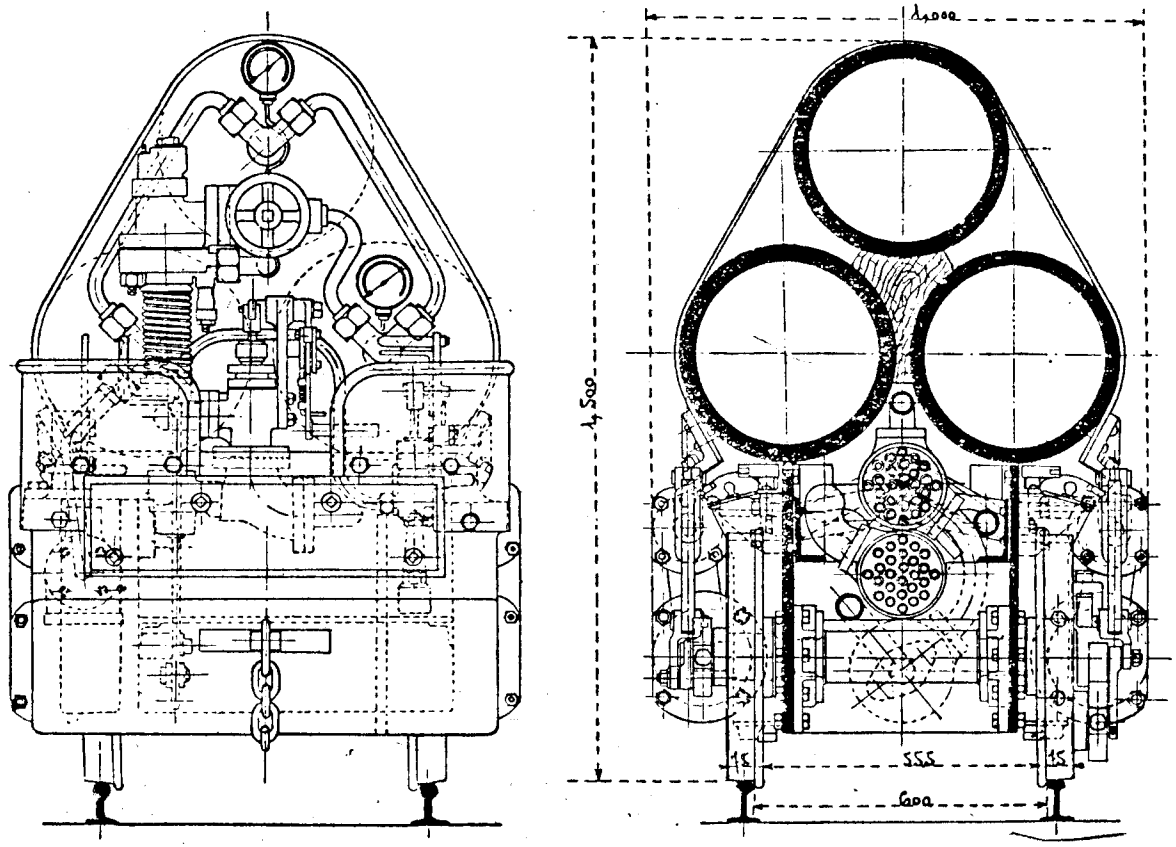


Fig. 3

Vue en bout : côté cabine — Coupe : A. B.

maintenus en place par deux butées, l'une à l'avant l'autre à l'arrière. Un dynamomètre est placé entre le crochet de traction AR et un point fixe.

Chaque arbre portant les galets est lié par un couple d'engrenages taillés à un moteur électrique à courant continu.

Les caractéristiques de l'installation sont les suivantes :

Diamètre des galets....	300 mm.	
Roue fixée sur l'arbre des galets, diam. primitif	480 —	60 dents
Pignon fixé sur le moteur, diam. primitif.....	115 —	14 —
Force maximum du dynamomètre.....	1.000 kg.	

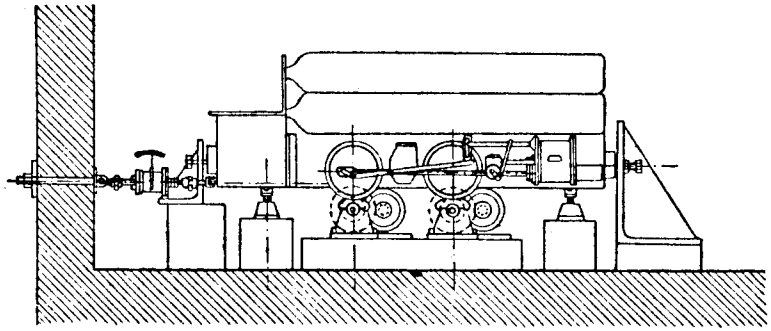
Flèche : 1 mm. pour 50 kg.

Caractéristiques des moteurs.

Excitation shunt.....	courant continu.
Vitesse normale.....	1.100 tours
Tension.....	200 volts
Puissance normale....	15 ch.

La Fig. 5 donne la courbe de rendement de ces moteurs.

DISPOSITIF D'ESSAI D'UNE LOCOMOTIVE AU POINT FIXE Echelle 1/75



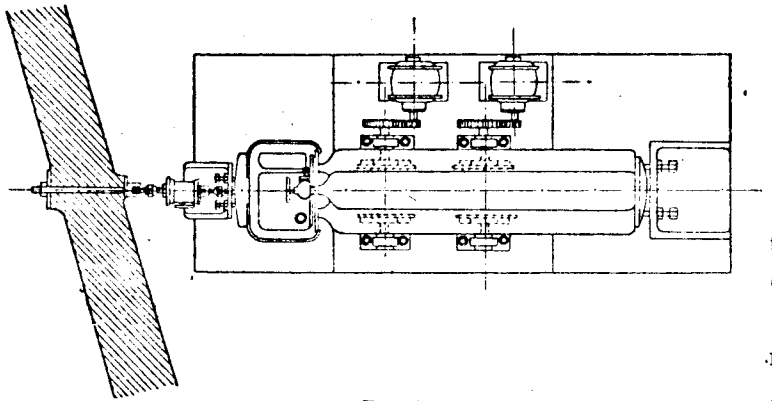


FIG. 4

Un totalisateur de tours est fixé sur la locomotive et un autre sur l'un des arbres portant les galets.

Programme des essais.

1° Essai de bon fonctionnement et de réglage.

2° Essai de consommation d'air à l'arrêt.

3° Mesure de l'effort de traction sur le crochet au démarrage.

4° Essai de puissance et de consommation.

1° ESSAI DE BON FONCTIONNEMENT ET DE RÉGLAGE.

Les deux moteurs sont branchés de manière à fonctionner comme dynamos à excitation séparée. Chaque dynamo débite sur une résistance liquide facilement réglable, un ampéremètre et un voltmètre branchés aux bornes indiquent la puissance développée.

Après avoir vérifié le fonctionnement du détendeur automatique qui doit maintenir à 25 kg. la pression dans le réservoir intermédiaire, la locomotive est mise en route et on fait, à différentes reprises, les manœuvres suivantes :

Changement du degré d'admission, arrêt, démarrage, changement de marche, essais des freins.

On constate que la machine obéit bien et que tous les organes de manœuvre fonctionnent dans de bonnes conditions.

Les FIG. 6 et 7 représentent les diagrammes relevés pour la marche AV et pour la marche AR avec même pression d'admission, même vitesse, même degré d'admission.

Ces diagrammes montrent que les compressions sont légèrement plus fortes pour la marche AR.

DM. PLATE-FORME D'ESSAIS

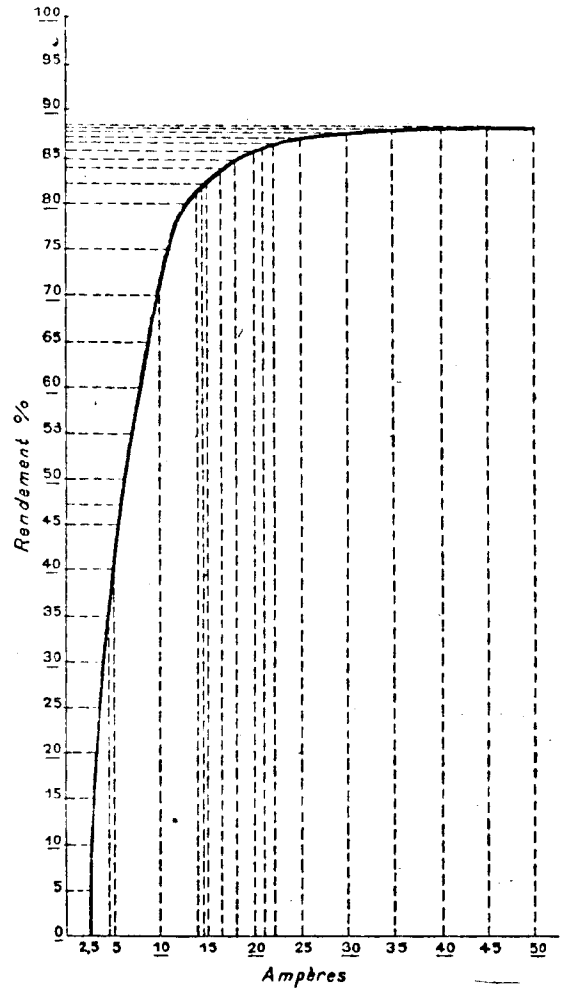


FIG. 5.

Moteur Thomson-Houston n° 100.768. — Type H_8.
Courbe de rendement à 1.100 t/m environ sous 220 volts.

MARCHE AV

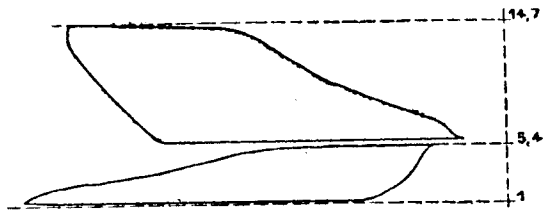


FIG. 6
Admission : 40 %.
Vitesse : 100 tours-minute.

MARCHE AR

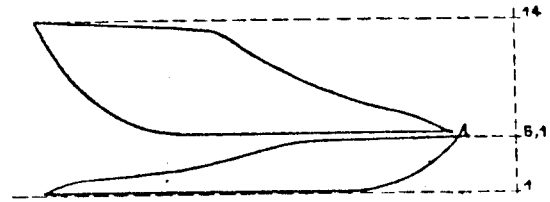


FIG. 7.
Admission : 40 %.
Vitesse : 115 tours-minute.

Les diagrammes 8 à 11 correspondent à un même sens de marche, même pression, même degré d'admission, mais vitesse différente.

MARCHE AV

FIG. 8.
Admission : 60 %.
Vitesse : 108 tours minute.

MARCHE AV

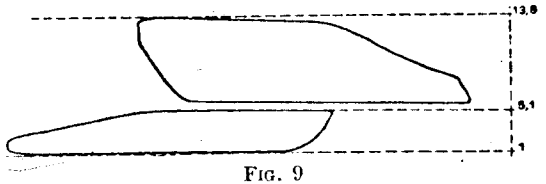


FIG. 9
Admission : 60 %.
Vitesse : 141 tours-minute.

MARCHE AV

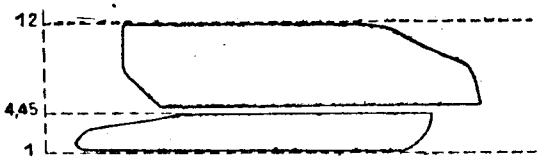


FIG. 10.
Admission : 74 %.
Vitesse : 107 tours-minute.

MARCHE AV

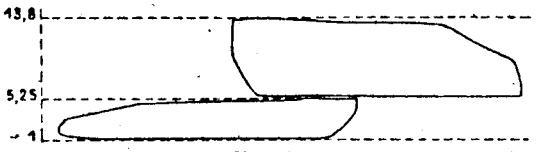


FIG. 11
Admission : 74 %.
Vitesse : 150 tours-minute.

On constate que les compressions sont un peu plus fortes à grande vitesse mais le remplissage des cylindres se fait bien.

2° ESSAI DE CONSOMMATION D'AIR A L'ARRÊT.

Cet essai a pour but de mesurer la quantité d'air perdu par fuites au travers des appareils et des joints de tuyauteries quand la machine est arrêtée, toutes les vannes et détendeurs ouverts, mais régulateur fermé.

Durée de l'essai : 1 heure;

Pression au début de l'essai : 73 kg. Température 15° 7 ;

Pression à la fin de l'essai : 70 kg. Température 15° 5 ;

Contenance des bouteilles : 960 litres.

La consommation d'air, ramené à la pression atmosphérique et à la température de 5° centigrades, est de :

$$960 \times 73 \times \frac{273 + 5}{273 + 15,7} -$$

$$960 \times 70 \times \frac{273 + 5}{273 + 15,5} =$$

$$67.500 - 64.760 = 2.740 \text{ litres.}$$

soit une consommation d'air par minute de stationnement

$$\frac{2740}{60} = 45^{l},7$$

et pour un stationnement de 8 minutes : 365 litres d'air à la pression atmosphérique.

La principale fuite constatée avait lieu au mano-détendeur, elle fut réduite après démontage par une révision de l'appareil.

3° MESURE DE L'EFFORT DE TRACTION SUR LE CROCHET AU DÉMARRAGE.

Pour faire cet essai, un dynamomètre est fixé d'une part au crochet de traction AR de la locomotive et d'autre part à un boulon scellé dans le mur de la plate-forme d'essai (FIG. 4)

Le dynamomètre taré accuse une flèche de 20 mm. pour une charge de 1.000 kg.

Un dispositif multiplicateur permet la lecture facile et exacte de l'effort exercé.

Pour faire cet essai, les galets sur lesquels la locomotive repose sont calés en insérant une résistance sur le circuit induit de chaque dynamo ; les butées de la machine vers l'avant sont reculées de 25 mm. environ pour permettre à la locomotive d'avancer.

On procède de la façon suivante :

Le levier de changement de marche étant placé à fond de course AV, on ouvre très légèrement le mano-détendeur et le clapet de démarrage, de manière à augmenter peu à peu les efforts sur les pistons : on lit sur le cadran du dynamomètre l'effort exercé.

Cet essai fut fait pour les différentes positions des manivelles motrices. Au-dessus de 750 kg. la machine patinait sur les galets et on ne put continuer les lectures.

Sur rails, ce chiffre de 750 kg. sera dépassé, surtout en faisant usage des sablières.

4° ESSAI DE PUISSANCE ET DE CONSOMMATION

On a d'abord mesuré :

a) La puissance absorbée par les frottements des organes de la locomotive, afin de pouvoir déterminer le coefficient de traction de la locomotive en ligne droite et en palier.

b) La puissance absorbée par frottement des axes des galets dans leurs paliers.

Le rendement des couples d'engrenages transmettant le mouvement aux dynamos ne pouvant être mesuré a été estimé à 0, 9.

On procède de la façon suivante :

Les machines électriques étant branchées en moteurs à excitation séparée, un rhéostat placé en dérivation sur le circuit de l'induit permet de régler l'intensité du courant dans l'induit. Un ampéremètre et un voltmètre donnent la puissance absorbée aux bornes du moteur. Le rendement du moteur est donné Fig. 5.

1° La machine reposant sur les galets, la vanne d'arrivée d'air fermée, le changement de marche à fond de course AV et les boulons de purge des cylindres enlevés pour qu'il n'y ait pas de dépression dans ceux-ci, les moteurs sont mis en marche pour entraîner les roues de la locomotive à la vitesse de 150 tours par minute dans le sens de la marche AV.

L'essai dura deux minutes pendant lesquelles le totalisateur de tours placé sur la locomotive indiqua un nombre de tours de 300.

On obtint les chiffres ci-dessous :

	Volts	Ampères	Watts	Rendement (voir fig. 5)	PUISSANCE	Puissance totale
Moteur A. V.....	216	13	2.808	0,81	$\frac{2.808 \times 0,81}{736} = 3$ HP 08	5 HP 33
Moteur A. R.....	220	10	2.200	0,75	2 HP 25	

Cette puissance correspond aux frottements des axes des galets dans leurs paliers et aux divers frottements du mécanisme (essieux, bielles, distributeurs, pistons).

2° On fit le même essai que le précédent après avoir enlevé les bielles motrices et les bielles d'accouplement.

De cette façon, les roues de la locomotive seules étaient entraînées.

On trouva :

	Volts	Ampères	Watts	Rendement Voir tableau n° 1	PUISSANCE	Puissance totale
Moteur A. V.....	220	10,5	2.310	0,76	$\frac{2.310 \times 0,76}{736} = 2$ HP 38	4 HP 76
Moteur A. R.....	220	10,5	2.310	0,76	2 HP 38	

La puissance développée sur les axes des galets est de : 4,76 × rendement couple d'engrenages = 4,76 × 0,9 = 4 ch., 28.

Cette puissance correspond aux frottements des axes des galets dans leurs paliers et aux frottements des essieux de la locomotive dans leurs boîtes.

Les boîtes d'essieux et les paliers des axes de galets supportent la même charge et sont placés dans les mêmes conditions de graissage, nature et état des surfaces frottantes.

On peut donc admettre, sans erreur sensible, que :

la puissance absorbée par les frottements des essieux de la locomotive est de :

$$\frac{4,28}{2} = 2 \text{ ch, } 14.$$

la puissance absorbée par les frottements des axes des galets dans leurs paliers est de :

$$\frac{4,28}{2} = 2 \text{ ch, } 14.$$

D'autre part, les différences de puissance développées par les moteurs sur les axes des galets dans les deux essais précédents représentent la puissance absorbée par les frottements des divers organes du mécanisme : bielles, pistons, distributeurs.

Elle est de : 4 ch, 8 — 4 ch, 28 = 0 ch, 52.

La puissance totale nécessaire à la locomotive pour se déplacer en ligne droite et en palier à la vitesse de 150 tours-minute, est de : 0,52 + 2,14 = 2 ch, 66, ou en kgm. seconde 2,66 × 75 = 200 kgm.

La force nécessaire pour la déplacer à 3,90 m

à la seconde, est donc de :

$$\frac{200}{3,90} = 51\text{ kg},300$$

ce qui donne un coefficient de traction par tonne de :

$$\frac{51,300}{6,5} = 7\text{kg},900$$

Tous ces essais ayant été effectués la locomotive tournant à 150 tours, nous avons par la suite tenu compte des chiffres trouvés, en les proportionnant au nombre de tours de la locomotive pendant l'essai considéré.

Après avoir procédé à ces premières mesures, on a fait les essais de puissance et de consommation.

Les machines électriques ont été branchées pour fonctionner comme dynamo à excitation séparée, le courant induit traversant une résistance liquide réglable.

On opérait de la façon suivante :

La locomotive étant mise en route, le changement de marche placé dans une position correspondant à un degré d'admission déterminé, on manœuvrait le mano-détendeur pour avoir la pression choisie à l'admission H P. Puis on réglait la résistance de chaque dynamo pour obtenir la vitesse convenable. Elle était mesurée à l'aide d'un compte-tours sur l'arbre d'une dynamo.

On faisait les lectures suivantes :

Pression et température aux réservoirs principaux.

Chiffre du totalisateur de tours de la locomotive.

Chiffre du totalisateur de tours de l'arbre des galets A R.

Volts et ampères aux bornes de chaque dynamo.

A la fin de l'essai, on faisait les mêmes lectures.

Un diagramme était relevé pour chaque essai sur le cylindre côté gauche.

1° *Essais à la vitesse maximun.* — A la vitesse de 150 tours par minute environ, on a obtenu :

Pression d'admission 14 kg. effectifs	admission 40 °/₀ essai n° 1
Pression d'admission 12 kg. effectifs	admission 60 °/₀ essai n° 2
Pression d'admission 15 kg. effectifs	admission 40 °/₀ essai n° 3
Pression d'admission 15 kg. effectifs	admission 60 °/₀ essai n° 4

2° *Essais à la vitesse moyenne.* — A la vitesse de 120 à 130 tours-minute environ, on a obtenu :

Pression d'admission, 14 kg. effectifs (admission 60 °/₀ essai n°5).

Pression d'admission, 14 kg. effectifs (admission 40 °/₀ essai n°6).

3° *Essais à faible vitesse.* — A la vitesse de 90 tours-minute environ, on a obtenu :

Pression d'admission, 14 kg. effectifs (admission 40 °/₀ essai n°7).

Ces essais sont résumés par le tableau Fig. 12 et ont donné lieu aux calculs suivants :

(see next page for Fig. 12)

Exemple : Essai n°1. — Puissance absorbée aux bornes des dynamos :

$$\frac{6,5 \times 220}{0,42 \times 736} + \frac{4,5 \times 220}{0,3 \times 736} = 9\text{ ch},117.$$

Puissance absorbée par le frottement des galets porteurs :

$$\frac{2.14 \times 146}{150} = 2\text{ ch},083$$

2 ch,14 étant la puissance absorbée par ces galets quand la locomotive tourne à 150 tours-minute.

Nous en avons déduit la puissance disponible sur les essieux de la locomotive (puissance effective).

$$9\text{ ch},117 + 2,083 = 11\text{ ch},2$$

Nous avons considéré ensuite les diagrammes relevés au cours de chaque essai (Fig. 13).

ESSAI N° 1

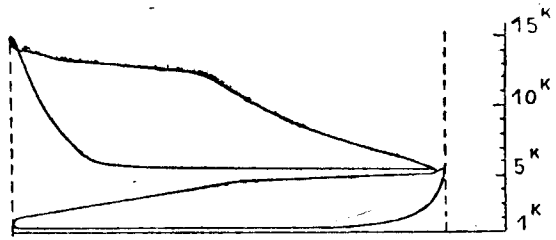
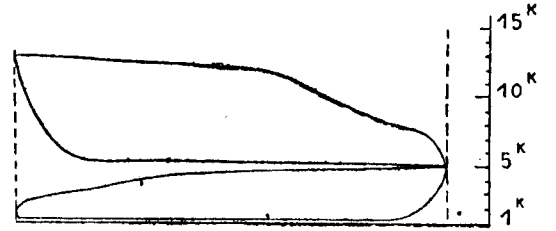


Fig. 13

Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm. 35 par m/m.
Ordonnée moyenne { HP : 4 kg. 24. BP : 2 kg., 70.
Introduction : 40 °/₀.

ESSAI N° 2

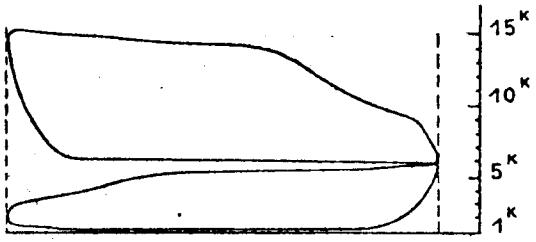


Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm., 35 par m/m.
Ordonnée moyenne { HP : 5 kg., 48. BP : 3 kg., 1.
Introduction : 60 °/₀.

FIG. 12 — RÉSULTATS DES ESSAIS DE LA LOCOMOTIVE A AIR COMPRIMÉ EFFECTUÉS AU POINT FIXE

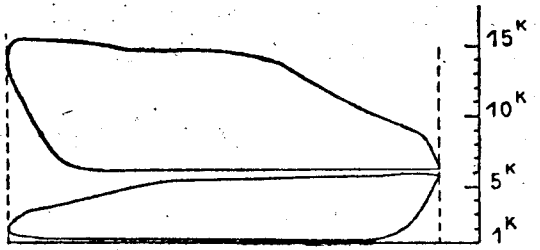
NUMÉRO DES ESSAIS	DURÉE DES ESSAIS	Débit d'air comprimé — Volumes des réservoirs : 960 litres — Pression barométrique pendant les essais : 712 m/m						VITESSE DE LA LOCOMOTIVE				VITESSE DES GALETS PORTEURS			GLISSEMENT	DYNAMOS RÉCEPTRICES						PUISSANCE EFFECTIVE		PUISSANCE INDIQUÉE			Puissance absorbée par les mouvements	Rendement mécanique	Consommation d'air par 10.000 kgm. effectifs	Pression effective d'admission aux cylindres H P
		Au début de l'essai		A la fin de l'essai		Consommation d'air à 5e et 1 kg.		Nombre au totalisateur	Nombre de tours total pendant l'essai	Nombre de tours minute	Chemin qui aurait été parcouru à la seconde	Nombre au totalisateur	Nombre de tours total	Nombre de tours minute		Nombre de tours minute	Puissance recueillie					Puissance absorbée par les galets porteurs	Puissance effective de la machine	Ordonnée moyenne H P	Ordonnée moyenne B P	TOTAL				
		Pression	Température	Pression	Température	Total	Par seconde										Volts	Ampères	Kilowatts	Rendement	Puissance sur l'arbre des dynamos								
		Kg.	Deg.	Kg.	Deg.	Litres	Litres				Mèt										Chev.	Chev.	Chev.	Kg.	Kg.	Chev.	Chev.		Lit.	Kg.
1	3'	79,5	15,3	68,5	15	10.818	60,1	6.357 6.795	438	146	3,82	10.311 11.041	730	243	0	1.041	220	6,5 4,5	1,43 0,99	0,42 0,3	9.117	2,083	11,2	4,24	2,7	14,06	2,86	0,796	715	14
2	3'	56,5	14,3	43	14	13.358	74,2	7.106 7.553	447	149	3,90	11.560 12.306	746	248	0	1.062	225	16,5 16,5	3,69 3,69	0,84 0,84	12	2,125	14,125	5,48	3,7	17,23	3,19	0,81	700	12,085
3	3'	50	14,5	32,5	14,2	17.354	96	8.388 8.849	461	153,6	4,02	13.701 14.469	768	256	0	1.097	230	18 24	4,14 5,52	0,85 0,87	15,23	2,19	17,42	6,72	3,62	21,164	3,74	0,825	733	15,400
4	2'	46,5	17	35	16,7	11.160	93	9.486 9.784	298	149	3,90	15.530 16.026	496	248	0	1.062	225	22 21	4,95 4,725	0,87 0,86	15,21	2,125	17,335	6,75	3,62	20,446	3,11	0,84	715	15,500
5	2'	65	18	55	17,8	9.847	82	11.181 11.439	258	129	3,37	18.354 18.784	430	215	0	921	190	20 21	3,8 3,99	0,86 0,86	12,30	1,84	14,14	6,61	3,25	16,55	2,41	0,85	775	14,200
6	2'	31	14,8	25	14,5	5.937	49,5	12.477 12.707	230	115	3,01	20.515 30.899	384	192	0	823	170	14 14,5	2,38 2,46	0,82 0,82	7,88	1,64	9,52	5,28	2,58	11,06	1,54	0,86	693	14
7	2'	29	17	22	16,8	6.878	57,3	13.996 14.174	178	89	2,33	23.041 23.338	297	145,5	0	615	135	22 22	2,97 2,97	0,87 0,87	9,28	1,27	10,55	7,12	3,36	12,02	1,47	0,88	724	14,500

ESSAI N° 3



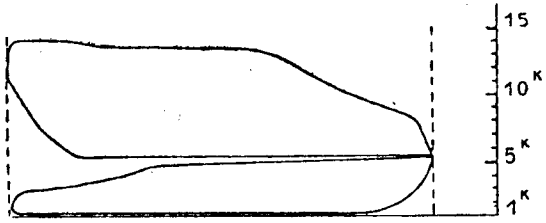
Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm., 35 par m/m.
Ordonnée moyenne { HP : 6 kg., 72. BP : 3 kg., 62.
Introduction : 60 %.

ESSAI N° 4



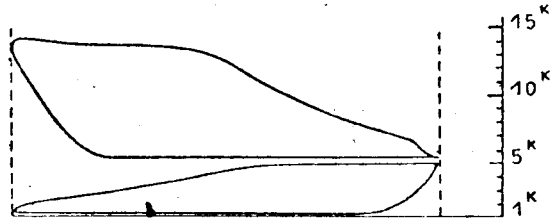
Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm., 35 par m/m.
Ordonnée moyenne { HP : 6 kg. 75 BP : 3 kg., 62.
Introduction : 60 %.

ESSAI N° 5



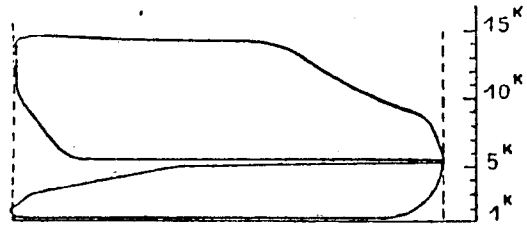
Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm., 35 par m/m.
Ordonnée moyenne { HP : 6 kg., 61. BP : 3 kg., 25.
Introduction : 60 %.

ESSAI N° 6



Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm., 35 par m/m.
Ordonnée moyenne { HP : 5 kg., 28. BP : 2 kg., 58.
Introduction : 40 %.

ESSAI N° 7



Echelle des pressions : 0 kg., 4 par m/m.
Echelle des courses : 3 cm., 35 par m/m.
Ordonnée moyenne { HP : 7 kg., 54. BP : 3 kg., 88.
Introduction : 60 %.

Nous avons calculé l'ordonnée moyenne de chaque phase et avons déduit la puissance indiquée, qui dans l'exemple présent est de 14 ch,06.

Nous en avons déduit le rendement mécanique :

$$\frac{11,\ 2}{14,06} = 0,796.$$

De la lecture des pressions d'air dans les réservoirs avant et après l'essai, nous avons obtenu la consommation d'air ramené à la pression atmosphérique et à la température de 5°.

$$\frac{79,5}{0,935} \times \frac{273 + 5}{273 + 15,3} - \frac{68,5}{0,935} \times \frac{273 + 5}{273 + 15} =$$

10.818 lit.

$$\text{Par seconde} = \frac{10.818}{180} = 60\ 1,1.$$

La puissance effective développée par la machine étant de 11 ch,2, nous avons obtenu la consommation d'air pour 10.000 kgm.

$$\frac{60,1 \times 10.000}{11,2 \times 75} = 715 \text{ lit.}$$

Nous avons procédé ainsi pour tous les essais.

En prenant une résistance à la traction de 5 kg. par tonne à la traction en palier pour les berlines et 7 kg. pour la locomotive, nous en avons déduit le tonnage kilométrique brut que nous aurions transporté pendant nos essais.

Le tableau suivant résume nos calculs :

Numéro de l'essai	Puissance effective	Distance qui aurait été parcourue pendant l'essai	Effort de traction sur le rail	Effort absorbé par la locomotive	Effort disponible au crochet	Charge remorquée en palier r = 5 kg.	Travail effectué en tkm. réellement transportée	Consommat. par tkm. transportée en palier
	C. V.	M.	Kg.	Kg.	Kg.	T.	Tkm.	Litres
1	11,2	687,6	220	51,3	168,7	33,74	23,2	466
2	14,125	701,8	271,5	51,3	220,2	44,04	30,9	432
3	17,42	723,8	327	51,3	275,7	55,14	39,9	435
4	17,335	467,8	333	51,3	281,7	56,34	26,35	423
5	14,14	405,0	314,5	51,3	263,2	52,64	21,3	462
6	9,52	361,1	237	51,3	185,7	37,14	13,4	443
7	10,55	279,6	339	51,3	287,7	57,54	19,5	352

Le réglage de la locomotive étant terminé au point fixe, M. Mazodier, le directeur distingué de la Société des mines de Roche-la-Molière et Firminy, nous a autorisé à faire descendre notre machine au puits Combes de cette Société. Nous voulions voir comment se comporterait pratiquement cette locomotive.

L'installation de traction mécanique de ce puits comprend :

En surface : 2 compresseurs d'air à 150 kg. capables chacun d'un débit de 5 m³ aspirés par minute, type Schwartzkopf.

Une batterie d'accumulateurs d'air comprimé avec déshuileur d'une capacité totale de 3 m³,100.

PUITS COMBES

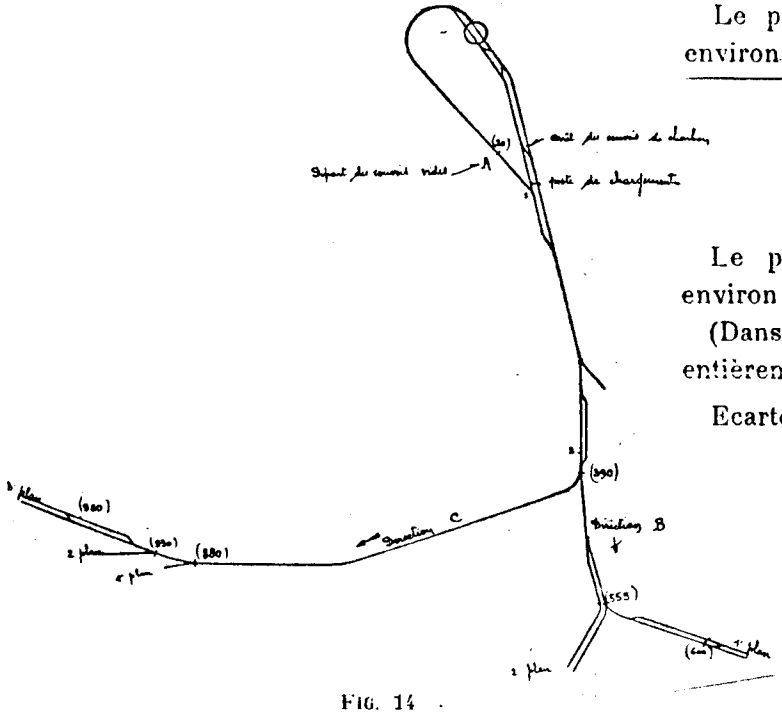


FIG. 14
Schéma des plans de roulage.

Au fond : 3 locomotives.

La FIG. 14 montre schématiquement l'installation des plans de roulage, ainsi que les distances des principaux points au poste de rechargement. La pente est de 7 °/₀₀ vers le puits.

Le service est assuré par trois postes.

7 h. à 15 h. — On mène des berlines vides aux chantiers et on ramène des berlines de charbon.

15 h. à 23 h. — On transporte des berlines de remblai et au retour des berlines de charbon.

23 h. à 7 h. — Service varié, transport de bois.

Le poids d'une berline vide est environ de 250 kg.

Le poids d'une berline de charbon est environ de 800 kg.

Le poids d'une berline de remblai est environ de 850 kg.

(Dans ce dernier cas les berlines ne sont pas entièrement remplies).

Ecartement des rails : 0 m,60.

Organisation du service de traction.

La locomotive étant au poste de chargement l'avant dirigé vers le puits, va par l'aiguille I, s'atteler au convoi de bennes vides au point A.

Elle s'arrête ensuite au point 2 où a lieu le croisement avec le convoi descendant, puis elle est aiguillée vers l'une ou l'autre des directions B et C.

Au point terminus, la locomotive est dételée et par une voie latérale elle passe à l'arrière du convoi qu'elle refoule jusqu'à dégager l'aiguille. Elle vient s'atteler ensuite au convoi de bennes de charbon.

La direction A dessert trois plans auxquels on répartit, suivant les besoins, les berlines vides, mais au premier et deuxième plans, la machine ne fait pas de manœuvre ; le convoi s'arrête pour laisser ou prendre des berlines qui sont trainées par des chevaux.

La direction B dessert deux plans et il y a manœuvre par la locomotive pour répartir les vides et prendre les pleines.

Les convois sont composés de la façon suivante :

36 berlines vides ou 15 berlines de remblai à l'aller ;

36 berlines de charbon au retour.

Etat des voies. — La pente de 7 °/₀, prévue pour les galeries n'est pas uniforme, ce qui n'a guère d'importance sur le parcours, mais aux endroits où le convoi s'arrête habituellement une pente trop faible rend les démarrages de convois chargés très pénibles. C'est ce qui se produit au point 880 et au point 600. A ce dernier la difficulté est encore augmentée par des courbes très prononcées et l'humidité de la voie.

CARACTÉRISTIQUES DE LA LOCOMOTIVE.

	Locomotive en essais	Locomotive Schwartzkopf
Type de la locomotive.....	Compound parallèle	Triple expansion
Largeur de la voie.....	600	600
Nombre de réservoirs.....	3	3
Capacité des réservoirs.....	960 litres	1 310 litres
Diamètre des roues.....	500	500
Empattement.....	1.000 mm.	1.000 mm.
Largeur maximum.....	1 m. 030	1 m. 030
Hauteur maximum.....	1 m. 500	1 m. 630
Longueur maximum.....	4 m. 225	4 m. 000
Pression aux réservoirs.....	100 kg.	100 kg.
Vitesse maximum par seconde.	4 m. 15	4 m. 5
Poids en ordre de marche....	6.500 kg.	6.700 kg.
Pression de travail.....	16 kg.	30 kg.
Réchauffage	2 réchauffeurs tubulaires	2 réchauffeurs tubulaires

MISE EN SERVICE DE LA LOCOMOTIVE.

La locomotive a été descendue le dimanche 17 septembre 1922.

Les premiers jours, la locomotive a été attelée à des convois de remblai.

A partir du mercredi, le service normal a été assuré par deux locomotives Schwartzkopf n° 3 et 4 et par la locomotive en essais.

Pour chaque voyage, on a noté soigneusement la pression dans les réservoirs principaux au départ et à l'arrivée, la pression à l'arrivée était lue lorsque la machine ayant terminé la manœuvre s'arrêtait au poste de chargement. On nota également la charge à l'aller et au retour en nombre de berlines.

Charbon *c*
Vide *v*
Remblai *r*

Avec ces chiffres on a calculé pour chaque voyage la quantité d'air dépensé (volume ramené à la pression atmosphérique et à 5°).

On n'a tenu compte ni des manœuvres, ni des arrêts et on a compté 1.000 mètres pour le trajet C et 600 pour le trajet B.

Les tableaux I, II, III donnent tous les résultats.

TABLEAU I

DATE	Heure départ	Direction	Pression au départ	Charge à l'aller	Charge au retour	Pression à l'arrivée	Heure d'arrivée	OBSERVATIONS	Consommat° d'air
18-9	»	B	100	14 r	13 c	42	»		55.800
»	»	C	90	15 r	35 c	33	»		54.800
19-9	9,40	B	90	35 v	33 c	45	10,2		43.200
»	10,11	C	88	36 v	37 c	25	10,39		60.500
»	11,15	C	92	34 v	36 c	30	11,40		59.500
»	17,7	C	95	14 r	21 c	40	17,52		52.800
20-9	7,49	C	95	24 v	35 c 1 v	30	8,29		62.500
»	8,40	C	96	34 v	36 c	25	9,58	Déraillement.	68.100
»	10,5	C	98	34 v	36 c	35	10,30		60.500
»	15,55	C	90	15 r	13 c	35	16,30		52.800
»	16,45	B	90	14 r	22 c	40	17,25		48.000
21-9	8	B	90	34 v	25 c 18 chariots	30	8,40		57.600
»	8,50	B	95	32 v	31 c 4 chariots	35	9,20		57.600
»	9,28	C	90	32 v	37 c	25	9,55		62.500
»	10,7	B	80	34 v	36 c	20	10,35		57.600
»	11,27	B	75	36 v	36 c	32	11,48		41.200
»	12	B	77	34 v	34 c	33	12.23		42.200
»	12,38	B	70	34 v	36 c	25	13,9		43.200
»	13,23	C	63	34 v	36 c	6	14		54.800
22-9	7,58	C	100	35 v	34 c	30	8,30		67.200
»	8,45	C	90	32 v	36 c	20	9,10		67.200
»	9,22	B	83	34 v	36 c	25	9,50		55.800
»	10,5	C	84	32 v	26 c	10	10,35		71.000
»	11,10	C	80	34 v	36 c	10	11,32		67.200
»	11, 5	C	103	36 v	36 c	25	12,20		74.000
»	12,32	C	87	35 v	36 c	25	13		59.500
»	13,12	B	74	37 v	33 c	30	13.33		42.200
»	14	C	63	36 v	35 c	8	14,21		52.800
									1.592.100

TABLEAU II

DATE	Heure départ	Direction	Pression au départ	Charge à l'aller	Charge au ret.	Pression à l'arrivée	Heure d'arrivée	Consommation d'air
				V	C			
23-9	7,45	B	98	34	25	36	8,15	59.500
»	8,30	B	100	20	26	48	8,52	50.000
»	9 »	B	102	36	27	50	9,20	50.000
»	9,35	B	101	34	33	47	10,5	51.900
»	11 »	C	87	30	36	31	11,27	53.800
»	11,35	B	105	30	25	57	11,50	46.000
»	12,2	C	106	25	32	32	12,30	65.200
»	12,40	C	91	30	27	20	13,15	68.000
»	13,22	B	90	35	28	35	13,50	52.800
»	14	C	80	35	36	15	14,25	62.300
25-9	9	C	100	25	36	30	9,30	67.000
»	9,40	C	90	36	36	30	10,10	57.500
»	10,25	B	100	36	36	46	11	51.900
»	11,15	B	95	36	34	40	11,25	52.800
»	11,35	B	105	36	36	40	12,10	62.300
»	12,25	C	100	35	36	38	12,50	59.500
»	12,57	C	90	32	36	30	13,30	57.500
»	13,41	C	95	36	27	20	14,05	72.000
»	14,15	C	75	36	20	15	14,35	57.500
26-9	8,12	C	105	27	36	35	8,40	67.200
»	8,57	C	91	36	36	10	9,35	75.800
»	9,55	C	105	36	36	32	10,20	70.000
»	10,30	B	102	34	36	45	10,55	54.800
»	11,15	B	100	35	36	40	11,45	57.500
»	12	B	105	36	36	48	12,18	54.800
»	12,25	B	95	35	40	41	12,50	51.900
»	13,08	C	100	36	36	37	13,33	60.500
»	13,44	C	110	36	36	43	14,10	62.300
								1.652.300

TABLEAU III

DATE	Heure départ	Direction	Pression au départ	Charge à l'aller	Charge au retour	Pression à l'arrivée	Heure d'arrivée	Consommation d'air
27-9	10	C	100	36 v	36 c	35	10,30	62.500
»	11	C	105	36	36	38	11,24	64.300
»	11,32	B	115	36	34	67	11,58	46.100
»	12,7	B	110	36	34	60	12,27	48.000
»	12,34	B	105	36	36	50	12,56	52.800
»	13,3	B	108	36	36	57	13,27	49.000
»	13,34	B	100	34	36	57	14	41.300
»	15,30	C	75	10	35	25	16,8	48.000
»	16,27	C	95	14 r	17	33	17	59.600
»	17,35	C	100	14	35	28	18,10	69.100
»	18,17	B	90	14	30	38	18,40	50.000
»	18,50	B	100	14	34	42	19,25	55.700
28-9	9,55	C	100	36 v	36	38	10,28	59.500
»	11,15	B	105	34	36	48	12	54.800
»	12,7	C	105	32	36	44	12,25	58.600
»	12,46	C	100	36	36	35	13,10	62.500
»	13,24	C	110	36	36	49	13,55	58.600
»	14,8	C	100	36	36	40	14,35	57.600
»	15,50	C	92	14 r	18	30	16,25	59.600
»	16,50	C	102	14	32	31	17,35	68.100
»	17,55	B	100	14	34	42	18,25	55.800
»	18,40	B	90	14	32	36	19,10	51.900
»	19,17	C	100	14	34	39	19,45	67.200
								1.300.600

Le tableau IV se rapporte aux locomotives Schwartzkopf n° 3 et 4.

Il est juste d'observer dans tout ce qui suit que la locomotive en essai était neuve, alors que les autres machines avaient déjà deux années de service.

Nous avons établi les tableaux V, VI et VII de comparaison en nous basant sur des parcours et des travaux de même grandeur.

Si nous comparons la totalité du travail fourni par chaque locomotive pendant le service du fond, nous obtenons le tableau comparatif suivant :

TABLEAU IV

Locomotives Schwartzkopf

DATE	Heure départ	N° machine	Direction	Pression au départ	Charge à l'aller	Charge au retour	Pression à l'arrivée	Heure d'arrivée	Consommat. d'air
19-9	16,53	4	B	100	16 r	19 c	50	17,18	65 500
»	17,52	4	B	105	12 r	22 c	45	17,55	78.500
»	»	»	»	»	17 v	»	»	»	»
20-9	8,11	3	C	97,5	20 v	34 c	40	8,53	75.200
»	8,23	4	B	90	16	34	45	8,50	59.000
»	8,57	4	B	100	36	29	44	9,14	73.200
»	9,4	3	C	90	36	40	40	9,35	65.500
»	9,48	4	B	87,5	34	40	30	10,15	75.100
26-9	11,53	4	C	90	36	36	32	12,27	76.000
»	12,32	4	C	100	36	36	34	13,3	86.500
27-9	11,42	3	B	80	35	35	27	12,3	69.500
»	13,50	3	C	95	36	36	27	14,8	89.000
»	13,20	4	C	87	30	35	35	13,40	68 000
»	14,5	4	B	100	30	34	42	14,30	76.000
»	15,9	4	B	105	16 r	1 c	50	16,40	72.000
»	17,20	3	B	87	16 r	0	50	17,40	48.500
»	18,5	3	B	100	16 r	35 c	35	18,35	85.000
»	19,5	4	B	100	16 r	26	42	19,40	76.000
28-9	11,22	3	B	100	30	34	44	12,3	73 200
»	12,20	3	C	95	34 v.	36	25	12,50	91.700
»	11,5	4	C	90	34	35	35	11,35	72.000
»	11,50	4	B	101	35	35	42	12,20	77.200
»	15,30	3	C	98	10	10	60	16,20	49.800
»	16,40	3	B	100	16 r	34	33	17,30	87.800
»	15,25	4	B	95	14 v	16 c	46	16,5	64.000
»	16,15	4	C	105	16 r	34	40	16,50	85.000

TABLEAU V

Parcours B (aller berlines vides, retour berlines de charbon) 600 m.

	Locomotive en essai	Locomotive Schwartzkopf n° 3	Locomotive Schwartzkopf n° 4
Date de l'essai	21 septembre 1922	20 septembre 1922	20 septembre 1922
Heure de départ de la locomotive	12 heures	9 h. 40	9 h. 19
Heure d'arrivée de la locomotive	12 h. 23	10 h. 05	9 h. 42
Nombre de berlines vides transportées	34	34	36
Nombre de berlines pleines transportées	34	32	32
Pression d'air au réservoir au départ	77 kg.	95 kg.	100 kg.
Pression d'air au réservoir à l'arrivée	33 kg.	45 kg.	45 kg.
Durée du parcours total	23'	25'	23'
Consommation d'air totale	42.200 litres	65.500 litres	70.800 litres
Poids total des trains remorqués :			
Aller	15 tonnes	15 t. 200	15 t. 700
Retour	35 t. 700	32 t. 100	32 t. 100
Tkm. totale	29,22	28,44	28,68
Tkm. utile	11,22	10,56	10,56
Consommation d'air par :			
Tkm. totale	1 445 litres	2.303 litres	2.468 litres
Tkm. utile	3.761 litres	6.202 litres	6.704 litres

TABLEAU VI

Parcours B (aller berlines de remblai, retour berlines de charbon)

	Locomotive en essai	Locomotive Schwartzkopf n° 3	Locomotive Schwartzkopf n° 4
Date de l'essai	28 septembre 1922	27 septembre 1922	27 septembre 1922
Heure de départ	17 h. 53	18 h. 05	19 h. 05
Nombre de berlines transportées :			
Aller	14	16	16
Retour	34	35	26
Durée du parcours	30'	30'	35'
Pression d'air aux réservoirs :			
Départ	100 kg.	100 kg.	100 kg.
Arrivée	42 kg.	35 kg.	42 kg.
Consommation d'air totale	55.800 l.	85.000 l.	76.000 l.
Poids total des trains remorqués :			
Aller	18 t. 4	20 t. 3	20 t. 3
Retour	33 t. 7	34 t. 7	27 t. 5
Tonne kilométrique totale	31,26	33	28,68
Tonne kilométrique utile	16,26	17,23	14,34
Consommation par tonne kilométrique totale	1.785l	2.575l	2.649l
Consommation par tonne kilométrique utile	3.430l	4.933l	5.298l

TABLEAU VII

Parcours C (aller vide, retour charbon) 1.000 m.

	Locomotive en essai	Locomotive Schwartzkopf n° 3	Locomotive Schwartzkopf n° 4
Date de l'essai	28 septembre 1922	27 septembre 1922	27 septembre 1922
Heure de départ	12 h. 07	13 h. 50	13 h. 20
Heure d'arrivée	12 h. 25	14 h. 08	13 h. 40
Durée du parcours	18'	18'	20'
Nombre de berlines :			
Aller	32	36	30
Retour	36	36	35
Pression au réservoir :			
Départ	105 kg.	95 kg.	87 kg.
Arrivée	44 kg.	27 kg.	35 kg.
Consommation d'air totale	54.800 litres	89.000 litres	68.000 litres
Poids total transporté ;			
Aller	14 t. 5	15 t. 7	14 t. 2
Retour	35 t. 3	35 t. 5	34 t. 7
Tonne kilométrique totale	48,9	51,2	48,9
Tonne kilométrique utile	19,8	19,8	19,25
Consommation par tonne kilométrique totale	1.120 litres	1.738 litres	1.390 litres
Consommation par tonne kilométrique utile	2.767 litres	4.494 litres	3.532 litres

	Consommation totale d'air	Tonnes kilométriques totales fournies	Consomat. p. tonne kilométrique totale Litres	Consommation en %
Locomotive en en essai	4.541.700	3.175,95	1.430	74,5
Locomotive Schwartzkopf	1.975.500	1.026,5	1.924	100

Avant la guerre, comme nous le disions au commencement de notre premier article du mois d'août 1922, la traction à l'air comprimé était l'apanage presque exclusif de la construction étrangère. En publiant les résultats que nous avons obtenus, nous voulons simplement prendre rang parmi ceux qui cherchent à secouer cette hégémonie et tentent un effort vers l'indépendance.

Compressed-Air Locos. in German Mines.

By E. Krahnen.

The employment of compressed-air locomotives for travelling long distances only became possible after weldless steel cylinders of a large size had been introduced, in which the amount of air necessary for working could be stored at a pressure of about 3,000 lbs. per sq. in. As this type of locomotive may be used with safety in all mines where firedamp or other dangerous gas is present, they are extensively used in the Ruhr coal mines.

In 1920 the mines in the Dortmund district employed 624 such locomotives, which hauled all told, about 15,000,000 tons of coal during the year, and thus had a considerable share in the total haulage by locomotive, which amounted in that region to about 57,000,000 tons. These locomotives, as shown in our illustrations, carry a number of weldless, high-pressure storage cylinders, held together at the rear end by a stout plate, and near the front by a strong strap, both the plate and strap being firmly secured to the underframe. For lowering the locomotive down a shaft, the storage cylinders as well as the driver's cab can be detached from the underframe. All fittings and valves are independent of the end-plate, and are so connected with the storage cylinders that shocks do not affect the tightness of the joints.

Most of these locomotives work on the compound principle. On leaving the high-pressure cylinder, the air is circulated round a nest of tubes through which the warm air of the mine is drawn. In this way the air which leaves the high-pressure cylinder at a temperature below 0 deg. C., due to its expansion, is warmed up to the temperature of the mine air before expanding further in the low-pressure cylinder. In service the air flows from the storage cylinders through a check valve and a pressure-reducing valve, which reduces the pressure to about 200 lbs. per sq. in. Before entering the high-pressure cylinder the air passes through a receiver. The distribution of compressed air can be regulated within wide limits by balanced piston valves and link motion just as in a steam locomotive. If, owing to being at the dead centre, the engine cannot be started otherwise, high-pressure air can be by-passed to the low-pressure cylinder. The whole driving gear is outside the loco frame, and is easy of access for repairs.

The driver's cab contains the levers for reversing the engine and for regulating admission, the brake lever, the sanding box and an alarm bell; also a small accumulator battery which supplies the low-tension current for the lamps. In case of emergency, the locomotive can be reversed, thus assisting greatly the retarding effort produced by the brake. By placing the storage cylinders in the positions shown, an opening is left which permits the driver to see the road in front without putting his head out of the cab.

With one charge of air the locomotive can travel a distance of about 6 miles. Including the air required for shunting and leaving a small reserve for cases of emergency, the extent of travel amounts to about 2 or 3 miles. The storage cylinders can be filled from the mine pipe-line. In most instances, tubes of 1¼ in. bore are used. The air can be taken at suitable points from these tubes by means of ½-in. steel tubes. Charging the locomotive, including connecting and disconnecting

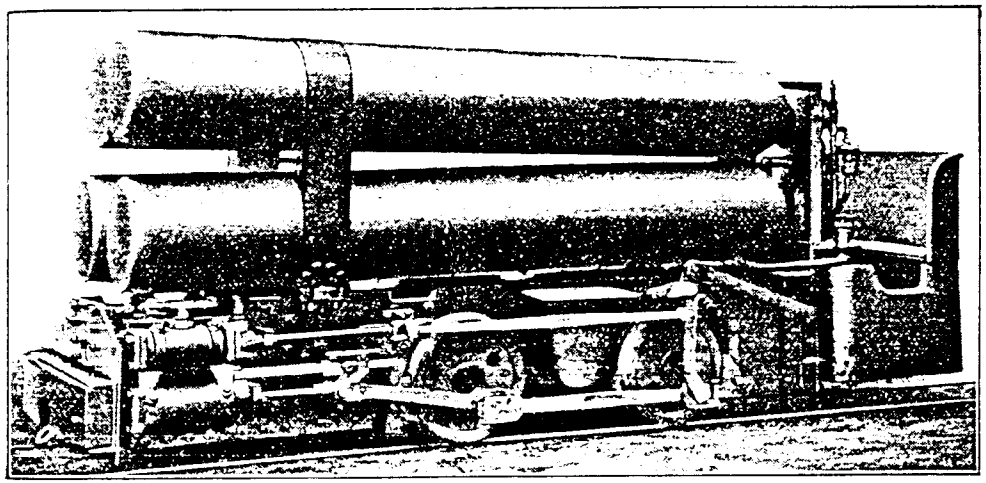


FIG. 1.—MAIN LOCOMOTIVE WITH STEEL TANKS ARRANGED IN AN INCLINED POSITION TO ALLOW THE DRIVER A FREE VIEW OF THE TRACK IN FRONT.

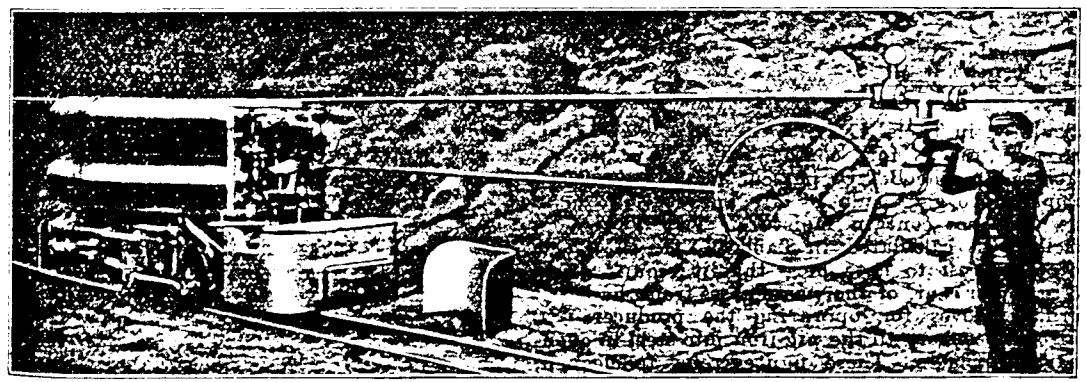
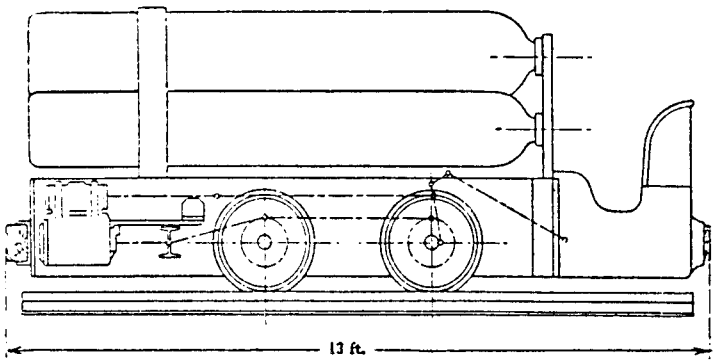
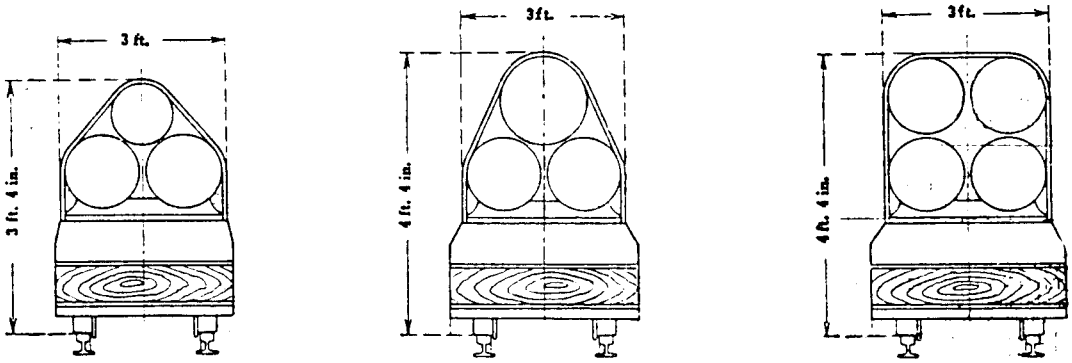


FIG. 2.—CHARGING A LOCOMOTIVE; SHOWING AIR LINE AND LIGHT STEEL CONNECTING PIPE.



Tractive Force = 1,000 to 2,200 lbs. (20-30 h.p.).



140 Galls. (4 Tons). 280 Galls. (6.5 Tons) 300 Galls. (7 Tons)

FIG. 3.—OUTSIDE DIMENSIONS OF COMPRESSED-AIR LOCOMOTIVES USED IN THE RUHR MINING DISTRICT

the pipe-line can be accomplished in about 1½ to 2 min. Small-bore tubes are recommended, as they can be easily shifted if required, and the flanged joints can be kept tight without difficulty. Pipe-lines of large diameter are not laid over long distances, even if the large capacity of such pipes might serve as air storage. Preferably, special arrangements are made for the storage of compressed air, consisting of a group of seamless cylinders, generally placed near the piping leading down the shaft or at some out-of-the-way place.

Such compressed-air locomotives are built either as main-road or gathering locomotives, and weigh from 3.5 to 7 tons. Their power is from 10 to 32 h.p. With a wheel base of 3 ft., curves as sharp as 20 ft. radius can be passed easily. More powerful compressed-air locomotives are used for tunnel work, and in plants exposed to danger from fire. By fitting a larger number of storage cylinders, the power of the engine can be increased as desired, but the general design remains practically the same as that of the locomotives described. If the engines are to be worked in a cold climate, the working air is heated by a coke or charcoal fire.

Compressed Air Haulage in the Coal Mines of Western Canada

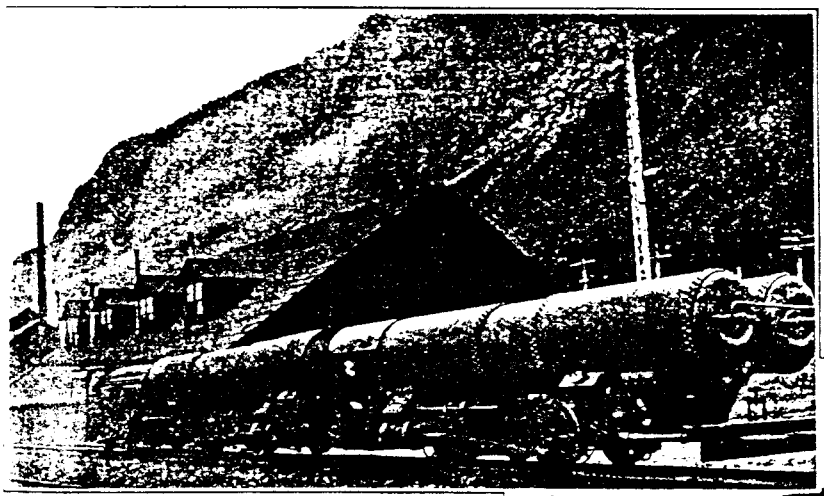
By S. A. WILLIAMS

The history of the compressed air locomotive for mine haulage dates back to 1873, and the use of this form of tractor was inspired mainly by a desire to obtain increased safety, reliability, and simplicity in this field of work. Indeed, the elements of safety and reliability have determined, in most cases, preference for compressed air haulage over electric traction. Only a few compressed air locomotives were built between 1873 and 1895, but in the thirteen years following several hundred single-expansion locomotives of this type were constructed principally for underground haulage in coal mines. From 1908 until the present time, a large number of 2-stage or compound compressed air locomotives have been built. The compound air locomotive is from 30 to 50 per cent more efficient than the single-expansion engine, and for that reason the majority of the installations since 1908 have been of the 2-stage or compound type.

The first air-haulage plant in western Canada was installed nineteen years ago at Coleman, Alberta, by the International Coal & Coke Company, Ltd. This plant consisted of a B2T compressor and three air locomotives built by the Canadian Rand Drill Company, Ltd., of Sherbrooke, Que., now the Canadian Ingersoll-Rand Company, Ltd. This compressor had duplex steam cylinders of 16-inch bore and 24-inch stroke and the air was compressed from atmospheric pressure to a final discharge pressure of from 1,000 to 1,200 pounds. The low-pressure air cylinder was 18 inches in diameter and had a stroke of 24 inches; and the air in this cylinder was compressed to from 25 to 30 pounds. The air was then passed through an overhead intercooler to the second-stage cylinder, of 10½-inch bore and 24-inch stroke, and compressed to about 100 pounds. Next, the air was carried through another intercooler to the third stage, at which it was compressed to about 375 pounds by a plunger of 9-inch diameter and 24-inch stroke, and finally passed through another intercooler on its way to the fourth and last stage. In this stage, a plunger of 5-inch diameter and 24-inch stroke compressed the air to the final discharge pressure of from 1,000 to 1,200 pounds. The first and the second-stage cylinders were double acting, that is, the air was compressed on both sides of the piston; and the third and the fourth stages were single-acting plungers — the air being compressed on one side of the plunger only. The third and the fourth-stage plungers were packed with metallic packing rings.

The air line consisted of a quantity of extra-heavy piping tested to a pressure of 1,800 pounds per square inch; and the charging stations were placed at the mouth of the mine and at partings. These charging stations were provided with flexible couplings so that the locomotives could be charged in a fraction of a minute. Of the locomotives put in service at Coleman in 1904, one had duplex cylinders of 6-inch bore and 10-inch stroke and the two others had duplex cylinders of 5-inch bore and 10-inch stroke. The air tanks carried by these locomotives were charged to a pressure of 800 pounds, and the air was passed through a reducing valve at a pressure of about 160 pounds. It then entered the cylinders, and, after performing its work there, was exhausted into the atmosphere. The grade of the track in this mine is about one-half of one per cent in favor of the loaded cars. The larger locomotive was used for the main haulage and the smaller ones for gathering the loads and for distributing the empties.

It is now nineteen years ago since this plant was obtained, and the compressor and two of the locomotives are still in continuous service. One of the locomotives was



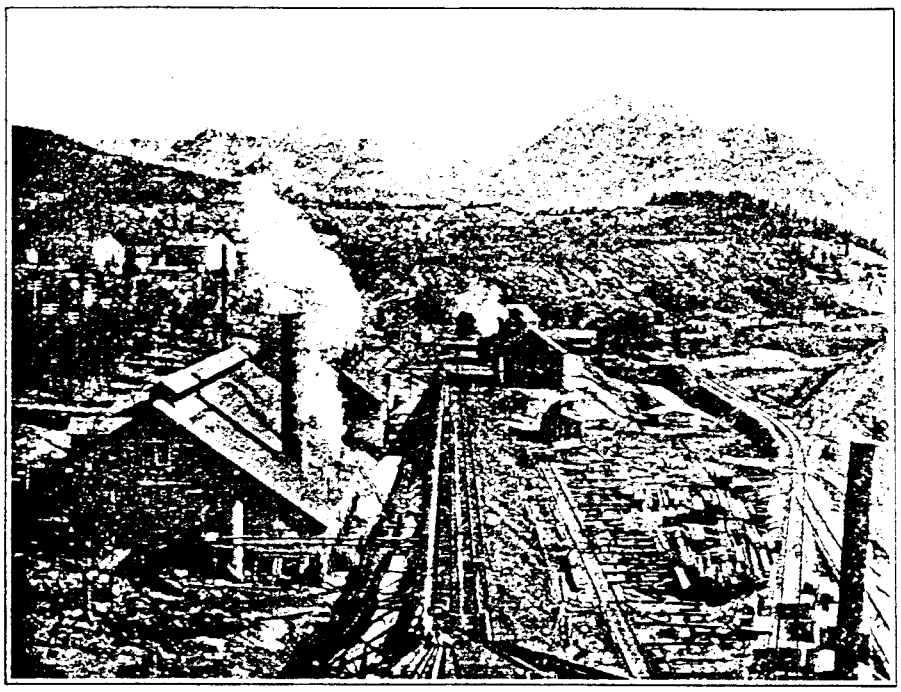
Double-tank type of compressed air locomotives, built in Canada, have been used for years at collieries in Alberta.

Close-up of the cab of a compressed air locomotive. The engineer's seat is low and it is easy for him to step out and onto the ground or vice versa.

damage [illegible] account of the greater efficiency of the 2-stage locomotive it was not deemed advisable to repair the injured unit. The power house was burned last fall, but the compressor was repaired and was again in running order in about a month. Since 1904, the International Coal & Coke Company has installed two more high-pressure compressors of the same capacity and has also put in service several 2-stage locomotives of the Porter type.

mines, together with several Porter locomotives.

About that time the West Canadian Collieries adopted air haulage in their mines at Lille, Alberta. They installed a high-pressure compressor and Porter locomotives. The H. W. McNeill Coal Company at Canmore, Alberta, and the Hosmer mines, Hosmer, B.C., next followed the lead, and then the Corbin Coal and Coke Company at Corbin, B.C., installed a cross-compound compressor and 2-stage air locomotives. These,



The Surface Workings of an Alberta Colliery.

In 1905, the Bankhead Mines at Bankhead, Alberta, installed a cross-compound, Corliss, steam-condensing air compressor, having a capacity of 1,346 cubic feet per minute, and compressed air locomotives of the double-tank type, all of which were built in Canada. In the same year the Crows' Nest Pass Coal Company equipped their No. 8 mine at Michel, B.C., for air haulage. This plant consisted of a Rand, Class B2T compressor and Porter air locomotives. In 1908, this compressor was sold and a cross-compound, Corliss condensing compressor, with a capacity of 1,346 cubic feet of air per minute, was substituted. Within the year, the Crows' Nest Pass Coal Company put a duplicate of the compressor at Michel in their Coal Creek

it is said, were the first 2-stage or compound locomotives in western Canada.

The 2-stage locomotive was designed to expand the air in two successive cylinders with an atmospheric interheater placed between them — the exhaust air from the high-pressure cylinder passing through this interheater on its way to the low-pressure cylinder. The in-

A 6x10 air-driven locomotive. One of the Units in the Service of the International Coal and Coke Coy. Coleman, Alberta.

terheater is constructed on lines similar to those of an intercooler on an air compressor, but instead of water a current of air from the surrounding atmosphere is drawn through the tubes. The temperature of the exhaust air from the high-pressure cylinder is about 140 deg. F. below that of the atmosphere. This air

surrounds the tubes in the interheater, and, in consequence, enters the low-pressure cylinder at nearly the same temperature as that of the atmosphere. The air entering the high-pressure cylinder has a pressure of about 250 pounds, while the air going into the low-pressure cylinder has a pressure of about 250 pounds, while the air going into the low-pressure cylinder has a pressure of about 50 pounds.

In 1913, the Jasper Park Collieries, Pocahontas, Alberta, installed a compressor and put in service three 6x12x12-inch Porter locomotives; and eight years later the McGillivray Creek Coal & Coke Company at Coleman, Alberta, decided to equip their properties for air haulage. It might be mentioned in passing, that Foley Brothers, Welsh & Stewart employed a compressed air haulage plant at each end of the Connaught Tunnel, at Rogers Pass, on the main line of the Canadian Pacific Railway. This is a double-track tunnel, five miles long. The locomotives were used to haul standard railway dump cars that were filled with rock by air-driven shovels working in the tunnel. Small air locomotives were also used to haul the muck out of the pioneer tunnels.

Compressed air haulage was chosen for this work only after a thorough investigation of the different types of haulage; and it is evident that this system came up to expectations, inasmuch as the tunnel was completed 364 days ahead of the specified time — the contractors earning a substantial bonus in consequence.

Compressed air haulage is simple, reliable, and efficient, and a man with ordinary intelligence can, in a very short time, become an expert "dinkey" runner. The smaller sized locomotives of this character will operate over curves having as much as a 12-foot radius. In gaseous coal mines, lumber yards, explosives factories, textile plants, etc., the compressed air locomotive assures a measure of safety that cannot be claimed for engines of other kinds, as evidenced by actual experience.

Several years ago, a mine in the Alberta district caught fire. The compressor was promptly stopped; a large pump was connected to the air line; and by thus converting the system into a water line the fire was put out. In cases of emergency, such as a breakdown of the regular low-pressure compressor plant, the high-pressure air can be reduced to 100 pounds and used to operate "Jackhamers" and direct-acting pumps. Out of a total of twelve air haulage installations in western Canada, the Canadian Ingersoll-Rand Company supplied the compressors for eleven — or a total of fifteen machines.

P.T. Davies 1924

Compressed Air Haulage. Compressed air haulage systems have been carried to a high state of development in Canada. In Alberta and British Columbia a number of two-stage locomotive systems are in use (see Plate 1), while in other sections stationary reciprocating air haulage engines are used to operate balanced or main and tail rope systems.

In actual practice, compressed air locomotives compare favourably with other types in convenience, efficiency and economy. Their outstanding virtue is the entire absence of fire hazard and of danger from electric shock, as well as the avoidance of noxious exhaust gases. The air locomotive is self-contained, and after the laying of track there is no supplementary rail bonding to be done, a particular advantage when the trackage is at best only temporarily needed. Modern air locomotives use air expansively in two stages and the manufacturers state that, except under unusual conditions, the cost of power to operate is no greater than that required for electric types.

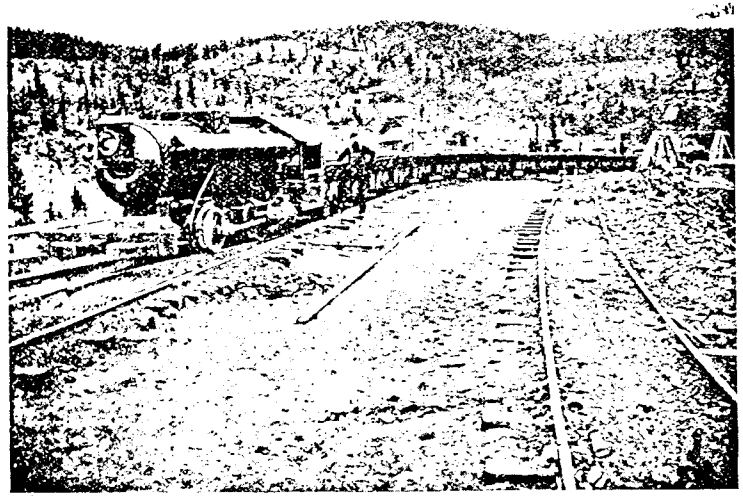


PLATE 1.
Locomotive and Train of Cars, International Coal & Coke Co., Coleman, Alberta.

In a paper read before the Canadian Mining Institute in 1916, the comparative cost of compressed air and horse haulage in a coal mine was given as follows :—

	Compressed Air.		*Horses.*
Labour	$0·046	..	$0·072
Supplies	0·017	..	0·022
Depreciation	0·015	..	0·015
Total cost per ton mile ..	··$0·078	..	··$0·109

These figures apply to a mine working under the following conditions : seams pitching 25 deg. or more ; pit cars containing two to three tons ; rails weighing 30 to 40 pounds per yard ; grades fluctuating but little from 0·46 to 1·00 per cent. in favour of the loads ; gangways roomy ; tracks fairly well kept ; curves few and slight.

The first air-haulage plant in western Canada was installed at Coleman, Alberta, by the International Coal and Coke Company, Ltd. The compressor has duplex steam cylinders of 16-inch bore and 24-inch stroke, and the air is compressed from atmospheric pressure to a final discharge pressure of from 1,000 to 1,200 pounds. The first and the second-stage cylinders are double acting and the third and fourth stages are single-acting.

The air line consists of a quantity of extra-heavy piping, tested to a pressure of 1,800 pounds per square inch ; and charging stations are placed at the mouth of the mine and at partings. These charging stations are provided with flexible couplings, so that the locomotives can be charged in a fraction of a minute.

It is now nineteen years since this plant was installed, and the compressor and two of the three original locomotives are still in continuous service.

Since this original installation, further plants have been installed at Bankhead, Lille, Calmene, Jasper Park and Coleman, Alberta, and at Michel, Hosmer and Corbin, B.C., and there are now in all twelve air haulage installations in use in Western Canada.

Continental Practice in Compressed-Air Haulage.

mong the many problems connected with the motion of efficiency and safety in colliery erground workings in recent years, probably

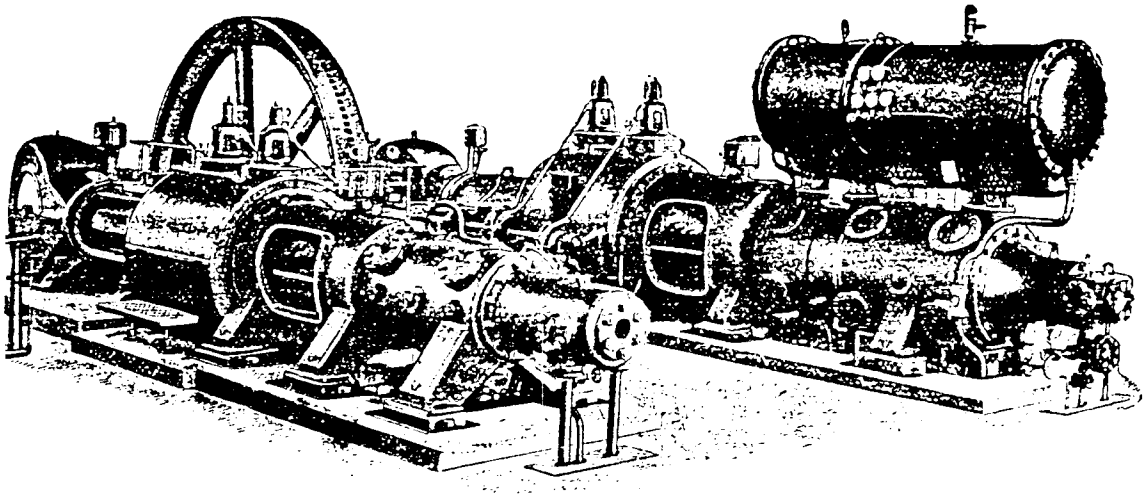


FIG. 1.—HIGH-PRESSURE, FIVE-STAGE, CROSS-COMPOUND COMPRESSOR FOR COLLIERY SERVICE, DIRECT-CONNECTED IN TANDEM TO COMPOUND ENGINE.

t has received quite so much attention and n with a view to improvement, as that of supply and transmission of power for the nport of coal to the shaft and surface, and of erials and tools to the working faces. Until t years the methods followed have been ly confined to animal, rope and electrical ge, each method having its own particular ntages and disadvantages.

hough for many processes in mining, com-ed air had been found one of the safest and convenient agents for transmitting power, is only in 1905, following operations in ca. that its use for traction in Europe e the subject of serious experiments. Since me, when locomotives having a single riveted and single expansion from 40 to 50 atmo-es were used, considerable advances have been Among the more notable improvements duced were (1) compounding the engines, (2) doption of triple expansion, and (3) increase working pressure to 150 or 200 atmospheres to 3,000 lbs. per sq. in.). The success of improvements may be gauged by the fact here are now in European mines upwards of

compressed - air ge plants, some of include as many om 20 to 30 loco-es.

a natural conse-e of these develop-s. it has been ary, not only to e suitable locomo-but to design ete plant capable ithstanding the y increased pres-and of efficiently buting the power ated. For these s a modern plant ists essentially of parts:—(*a*) Com-or units and e; (*b*) pipe lines; ing stations, and

comotives.

Compressor units ch may be steam-, or electrically-—have followed n multi-stage ce for high pres-and one of the modern types is a age cross-com-compressor (Fig. ect-connected in m to a compound e and capable of ressing 30 cubic s (1,060 cub. ft.) e air per minute pressure of 200 spheres (3,000 lbs. sq. in.). A single flywheel is used the combined pres-on each side imately balance;

first, second and fifth stages being on one side the third and fourth on the other. Coolers arranged between the various stages, those een the first and second stages being of the surface-condenser type, and the higher stages of the coil type.

(*b*) Pipe lines ranging in diameter from 30 to 50 mm. (say, 1.2 to 2 in.), according to the nature of the installation, as a general rule need only be run to conveniently situated filling stations near the shaft or adit entrance. It is not necessary to

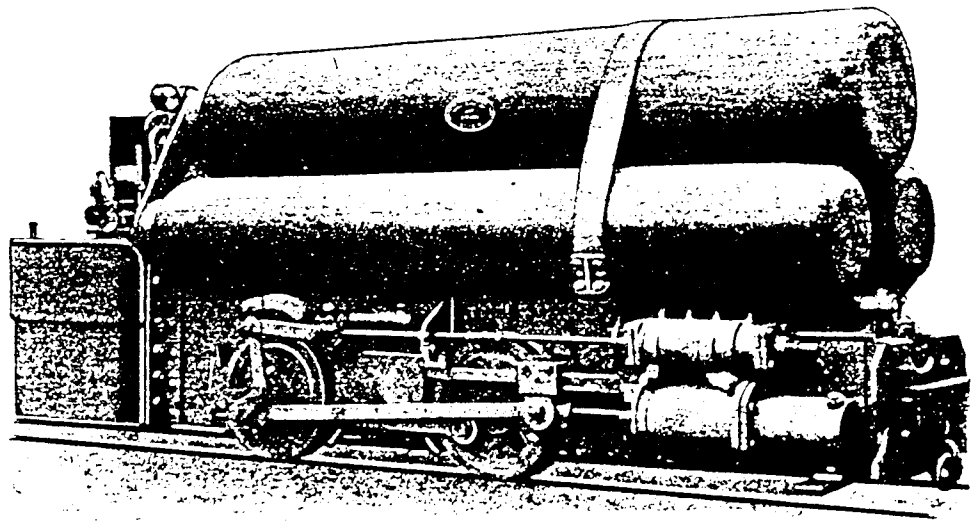


FIG. 2.—TRIPLE-EXPANSION COMPRESSED-AIR LOCOMOTIVE WITH THREE AIR CONTAINERS.

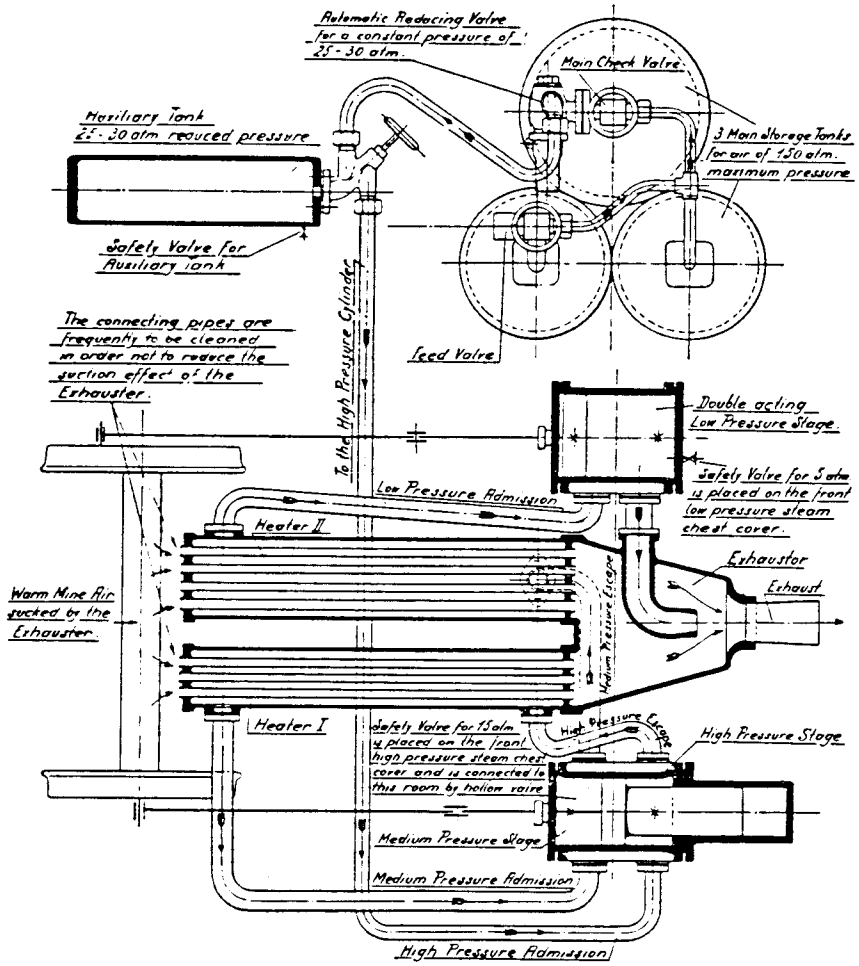

Automatic Reducing Valve for a constant pressure of 25-30 atm.
Main Check Valve
Auxiliary Tank 25-30 atm reduced pressure
3 Main storage Tanks for air of 150 atm. maximum pressure
Safety Valve for Auxiliary Tank
The connecting pipes are frequently to be cleaned in order not to reduce the suction effect of the Exhauster.
To the High Pressure Cylinder
Feed Valve
Double acting Low Pressure Stage.
Safety Valve for 5 atm is placed on the front low pressure steam chest cover.
Low Pressure Admission
Heater II
Exhaustor
Exhaust
Warm Mine Air sucked by the Exhauster.
Medium Pressure Stage
Heater I
Safety Valve for 15 atm is placed on the front high pressure steam chest cover and is connected to this room by hollow waire
High Pressure Stage
Medium Pressure Stage
Medium Pressure Admission
High Pressure Admission

FIG. 3.—EXPLANATORY DIAGRAM OF TRIPLE-EXPANSION COMPRESSED-AIR LOCOMOTIVE WITH DOUBLE INTERMEDIATE HEATING.

carry long pipe lines into the workings, as the radius of action of the locomotives is sufficient to enable them to operate from a central point. Pipes must not be galvanised, and must be of the best material tested to at least 1.5 times the working pressures.

(*c*) Charging stations—comprising suitable charging valves, flexible steel or copper charging connections, and screw caps—are placed at convenient points in the roadways. The main storage battery, consisting of a series of solid-drawn steel bottles, is preferably placed in the vicinity of the compressors and is usually of sufficient capacity to charge a locomotive in one to one and a half minutes.

(*d*) Locomotives—of two types, compound and triple-expansion—are supplied in various powers to suit local conditions affecting each particular installation, a compact triple-expansion type being shown in Fig. 2, which illustrates a locomotive in use at the mines of the Cie des Mines de Roche-la-Molière et Firminy, Firminy (Loire), France. In these locomotives a patented system of warming by means of mine air is adopted, and this system is indicated in diagrammatic form in Fig. 3, which also shows the triple-expansion cycle of operations. The high-pressure cylinder is differential in type, being designed for two-stage expansion with a heater between the stages. The low-pressure cylinder is designed for both sides to take air exhausted from a heater fed by the second stage of the high-pressure cylinder. By the insertion of a reducing valve the air admitted to the high-pressure piston is kept down to 20-30 atmospheres (300 to 450 lbs. per sq. in.).

The compound-type locomotive has two ordinary cylinders, high- and low-pressure, with a single heater between. In both types the piston diameters are such as to make the torques on each side of the engine equal. In operation, by compounding, a saving of 30 per cent. is effected over the single-expansion type, and a further saving of 25 per cent. is effected by the triple-expansion over the compound type.

The general advantages claimed for compressed-air locomotives over other systems of mechanical traction may be summarised as follows:—(1) Complete safety in firedamp, as there is neither combustion nor sparking. (2) No deterioration of the mine air, but on the contrary a continuous supply of fresh atmospheric air. (3) No dangerous electric-current conductors, no ropes, pulleys, chains, etc., and entirely unobstructed roadways. (4) Simplicity in operation, as no skilled drivers are required, and the compressor engineer is able to superintend other machines besides. (5) Maximum flexibility of plant in relation to variations in conveyance, so that operation is economical in every respect. (6) Minimum costs for maintenance, few repairs required, no considerable standby necessary, constructions rugged and simple, and therefore cheap in operation.

For the data in this article and for the illustrations we are indebted to Messrs. Christmas & Walters, Ltd., Caxton House, Westminster, S.W.1.

U.S. Fuel Reserves.—In the course of a report on fuel problems, drawn up by a Committee of American experts for submission to the meeting of the International Chamber of Commerce, at Brussels this month, suggestions are made for conserving the remaining solid fuel supplies in the States. It is pointed out that imports of liquid fuels may postpone their exhaustion for several decades, but it seems quite probable that by 1950 much the greater part of the natural liquid and gaseous fuels will have practically disappeared. The Committee makes numerous proposals for conserving the country's reserves of coal.

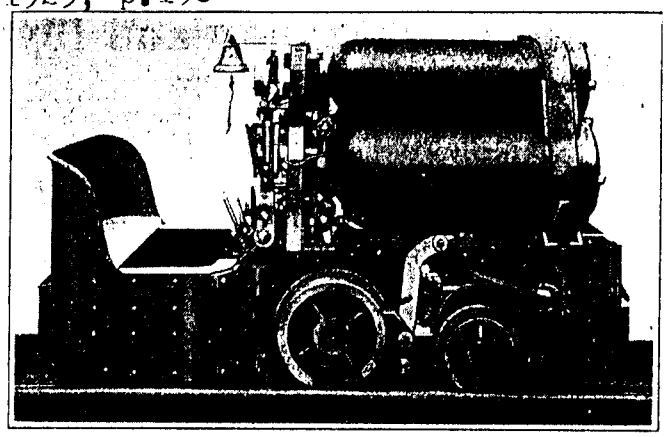
ENGINEERING AND
MINING JOURNAL-PRESS
August 1, 1925, p.196
Vol. 120, No. 5

Small Compressed Air Locomotive

A small mine locomotive, which is illustrated in the accompanying cut, has recently been developed by Messrs. Demag, of Duisburg, Germany, where it has been used in coal-mining operations, though not necessarily limited to this class of work.

In its design dimensions have been reduced to a minimum. It can be moved onto the cage without dismantling further than removing the driver's seat. This is a small sheet-metal casing, without fittings, which can be easily attached or removed. It can be readily moved from level to level or to the surface for repairs. Attention has also been paid to reducing the weight of the engine so that it may be used on the lightest rails in the furthest workings. The locomotive is able to haul 16 to 20 tons, depending on conditions.

Locomotive used in coal mines in Germany, which is so small it goes into the cage without dismantling



Reservoirs of 7 to 9 cu.ft. capacity are sufficient for covering a distance of 4,000 ft. going and returning with the load mentioned and at a loading pressure of 2,200 to 2,500 lb. per square inch. A compound compressed air engine with intermediate heating of the working air is used for driving. Other data of the locomotive are as follows:

Weight, empty, tons	2
Speed, miles per hour	4 to 6
Traveling pressure in cylinders, lb. per sq.in.	205 to 235
Useful performance, tons per mile per hour	7.2
Width of engine, in.	31½
Number of axles	2
Output normal, hp	4
Output maximum, hp	6
Pull normal, lb	330
Pull maximum, lb	550
Length of engine, in.	78¾
Height of engine, in.	49
Axle distance, in.	20½

December 1, 1925] BRENNSTOFF- UND WÄRMEWIRTSCHAFT. 467

Ueber Druckluftlokomotiven.

Von Ingenieur E. Herms.

Die Druckluftlokomotiven werden in den letzten Jahren in Bergwerksbetrieben aller Art den anderen Triebkräften vorgezogen. Der Bau dieser Lokomotiven mit großem Fahrbereich wurde jedoch erst nach Einführung nahtloser Stahlflaschen ermöglicht, in denen die zu einem wirtschaftlichen Betriebe notwendige Luftmenge mit der hohen Pressung von 250 at aufgespeichert wurde.

Da sich für die Streckenförderung unter Tage die Druckluftlokomotive am besten eignet, mußte man auf die Durchkonstruktion derselben ganz besonderen Wert legen. Selbst bei Schlagwetter in Steinkohlengruben kann man die Druckluftlokomotive ohne Gefahr verwenden, da diese durch den Auspuff die Luft verbessert und wegen ihrer geringen Bauhöhe auch niedrige Stollen befahren kann.

Auf den Zechen des Oberbergamtsbezirkes Dortmund befanden sich beispielsweise im Jahre 1920 insgesamt 634 Druckluftlokomotiven in Betrieb, die rund 13 Mill. t Kohle förderten und damit einen sehr erheblichen Anteil an der 37 Mill. t betragenden Gesamtlokomotivförderung gewonnen hatten.

Der Bergwerksbetrieb verlangt eine kräftige, betriebssichere Lokomotive, deren Einzelteile sich beim Befördern in die Grube bequem im Förderkorb unterbringen und schnell und leicht unter Tage montieren lassen. Die Druckluftlokomotiven werden für Grubenbetrieb in der Hauptsache in drei Größen gebaut, und zwar als Normallokomotiven für den Verkehr in den Hauptquerschlägen zum Befördern langer Züge zum Schacht, dann als Zubringerlokomotiven für den Verkehr in den Nebenstrecken und zum Zusammenstellen zu Hauptförderzügen und als sogenannte Vorort- oder Zwerglokomotiven, zum Wegschaffen der Kohle unmittelbar vor Ort. Die Druckluftlokomotiven bestehen gewöhnlich aus drei Teilen, dem Untergestell, dem Druckbehälterbündel und dem Führerstand. Diese drei Teile lassen sich unter Tage schnell und sicher zusammensetzen.

Die Druckluftlokomotiven werden für alle üblichen Spurweiten gebaut. Das Untergestell besteht entweder aus flußeisernen Längs- und Querblechen oder wird je nach Größe desselben aus Gußeisen oder Flußeisenformguß gegossen. Das Triebwerk, die Zylinder und die Steuerung werden je nach der größten Lokomotivbreite innen oder außerhalb des Rahmens angeordnet. Auf dem Untergestell ruht das Behälterbündel, das aus drei, vier, fünf oder mehr nahtlosen Stahlflaschen bestehen kann. Letztere werden

auf dem Untergestell mittels zwei oder drei kräftigen Zugbändern befestigt, um ein Verschieben dieser Flaschen in der Längsrichtung bei Stößen und Entgleisungen zu verhindern. Die Anordnung von mehr als vier Stahlflaschen mit kleinerem Durchmesser bietet den Vorteil, daß der Schwerpunkt der ganzen Lokomotive tiefer liegt und beim schnellen Durchfahren der Kurven bei kleinen Spurweiten ein Kippen verhindert wird. Verbindungsrohre und Flanschen, die bei den ständigen Erschütterungen leicht undicht werden, sind wegen der hochgespannten Druckluft nach Möglichkeit zu vermeiden. Die Flanschen der Flaschenhälse schraubt man auf eine 20 mm dicke Stahlplatte, durch deren Kanäle die einzelnen Behälter untereinander verbunden sind.

Die im Behälterbündel mit 100—175 at aufgespeicherte Druckluft wird durch einen Hauptabsperrhahn über ein Druckminderventil, das den Druck auf 10—14 at drosselt, in einen darunter liegenden Arbeitsluftkessel geleitet, der von vielen dünnwandigen Rohren durchzogen ist, durch die während der Fahrt die warme Grubenluft als eine kostenlose Vorwärmequelle für die durch den plötzlichen Spannungsabfall stark abgekühlte Luft strömt. Von hier wird die Luft durch ein Fahrventil für den Hochdruckzylinder entnommen, welche denselben mit etwa 3 at nach der Arbeitsleistung wieder verläßt, um durch einen Zwischenwärmer gleicher Bauart des Arbeitsluftkessels in den Niederdruckzylinder zu strömen, wo sie schließlich bis auf nahezu Atmosphärendruck ausgenutzt wird. Durch den ersten Vorwämer wird das in den Hochdruckzylinder eintretende Luftvolumen auf annähernd gleicher Größe erhalten und ein geringerer Luftverbrauch als bei den früher üblichen Zwillingsmaschinen erzielt. Durch beide Vorwärmer wird außerdem das Vereisen der Zylinder vermieden. Durch die Exhaustorwirkung der ausströmenden Luft aus dem Niederdruckzylinder wird das Durchströmen der Grubenluft durch die Vorwärmer noch beschleunigt.

Ueber 10—14 at Arbeitsdruck ist der Temperaturabfall im Zylinder und ferner der Luftverbrauch zu groß. Das Fahrventil ist häufig so eingerichtet, daß es normal für einen Betriebsdruck mit 6 at in den Zylindern zu arbeiten gestattet, um dadurch einen sparsamen Luftverbrauch zu ermöglichen. Nur für Lastfahrten bergaufwärts und wenn vorübergehend ein höherer Druck in dem Zylinder gebraucht wird, steigert man den Einströmungsdruck bis auf 14 at.

Die aufgespeicherte Luft reicht für eine Fahrstrecke je nach Größe der Lokomotive von 2—6 km. Das Füllen erfolgt mit einem 12 mm lichten Stahlrohr und nimmt einschließlich Verbindung und Lösen der Schrauben ungefähr 2 Minuten in Anspruch.

Die Druckluftlokomotiven werden als Zubringer- und Querschlaglokomotiven mit einem Gewicht von 2—20 t gebaut, Die Leistung beträgt 10—150 PS bei einer Höchstgeschwindigkeit von 5—12 km/Std.

Bei einem Radstand von 800—950 mm können Kurven bis herab zu 6 m Radius befahren werden. Große Maschinen sind im Tunnelbau und feuergefährlichen Betrieben sehr begehrt. Durch größere Behälterzahl und Behälterlänge kann die Leistungsfähigkeit auf jede gewünschte Höhe gebracht werden. Sobald die Maschinen bei niedriger Temperatur arbeiten müssen, wird zur Erwärmung der Arbeitsluft eine rauchlose Koks- oder Kohlenfeuerung vorgesehen. Für Signale befindet sich auf dem Führerstande eine Handglocke.

Neuerdings sind Zwergdruckluftlokomotiven gebaut worden, bei denen nur der Führersitz abgenommen wird und die Lokomotive im übrigen mittels Förderkorb in die Grube befördert werden kann. Der Führersitz ist ein kleiner Blechkasten, in dem keinerlei Armaturen untergebracht sind und der vom Führer leicht an- und abgehängt werden kann, ohne daß Rohrleitungen u. dgl. gelöst werden müssen. Hierdurch entsteht eine Reihe Vorteile. Einmal kann die Lokomotive während einer Schicht auf verschiedenen Fördersohlen benutzt werden, indem sie mit dem Förderkorb wie jeder Förderwagen von einer Sohle zur anderen gebracht wird. Außerdem kann die Lokomotive im Fall einer notwendig werdenden Ausbesserung schnell über Tage befördert werden, wo die Arbeiten viel schneller und besser auszuführen sind als in der Grube. Diese Zwerglokomotiven haben ein kleines Gewicht, damit sie auf den schwächsten Schienen bis in die entlegensten Orte verkehren können. Das Gewicht ist kaum größer als das eines beladenen Förderwagens neuester Bauart und beträgt etwa 2 t. Die Dauerzugkraft ist 150 kg, die größte 220 kg, so daß die Zwerglokomotive je nach dem Laufwiderstand der Wagen, 8—10 Wagen ziehen kann. Die Luftbehälter von 0,2—0,25 cbm Größe genügen, um bei einem Fülldruck von 150 175 at bei der angegebenen Belastung eine Strecke von 1200 m hin und zurück zu durchfahren. Der Antrieb dieser Zwerglokomotive erfolgt durch eine Verbundmaschine mit Zwischenerwärmung der Arbeitsluft. Die Lokomotive hat ein Leergewicht von 2 t und fährt mit 7—10 km Geschwindigkeit/Stunde. Der Fahrdruck im Zylinder beträgt 14—16 at. Die Lokomotive hat eine Nutzleistung von 12 Nutztonnen/Kilometer je Stunde.

Table 11. Compressed-air Haulage Plants

Compressor 3-stage		Air line		Locomotives			Total cost	Round trip, ft	Train, tons		Cost, ¢ per net	
Cu ft free air per min	Press., lb per sq in	L'gth, ft	Diam, in	No cyl	Size cyl, in	Wt, tons			gross	net	ton	ton-mile
(a) 375	700	9 600	4	2	7×14	8	$13 673	5 100	62.4	42	...	1.875
(b)	....	4 200	5	2	...	...	13 701	3 200 5 200	...	...	3.6	...
(c)	700	4 100	....	1	9×14	...	.....	9 000	87.7	...	...	1.25*
(d) 296	600	7 500	5 & 3	2	7×14	8	15 156	8 000 4 200	147.0	...	...	1.39 3.05
(e) 450	1 000	5 000	4	2	...	...	15 800	.....	...	...	...	2.17

* Gross. (a) *Mines & Min*, Vol 18, p 538. (b) Baldwin Locomotive Wks. (c) Peele, Compressed Air Plant. (d) Morris, *Trans* A I M E, Vol 30, p 566. (e) Two-stage locomotive, operating cost, int and deprec, 2.17¢ per ton-mile, as against 2.56¢ for single-stage, with coal @ $3 per ton (estimates by H. K. Porter Co).

Coal mines of western Pa and West Va were using 150 compressed air locos in 1921 (38). In U S metal mines, the only important compressed air haulage plants now operating are at Homestake mine, S D, and Inspiration mine, Ariz (42).

27. Compressed-air Locomotives (3)

Note.—Sec 11 deals with all means of Underground Transport, including electric and gasolene locomotives (see also Sec 16). Sec 15 treats of compressed-air locomotives only.

Field of work. This type of locomotive is adapted to all mines having compressed-air plant, and especially to gassy collieries or dry, timbered mines, in which electric or fuel-burning machines might be dangerous. ADVANTAGES: since the power is stored in the locomotive itself, it can operate wherever track is laid, returning at intervals to charging station; no trolley wires, with their attendant danger, are needed; no power consumed when the locomotive is idle; the exhaust tends to aid ventilation; power, greatly in excess of the average, is obtainable by temporarily using full tank press in the cylinders (3). But electric locos are generally more economical in running cost, if electric power is already installed for other service. For any given case, local conditions must be analyzed; data aiding in making choice are obtainable on request from H. K. Porter Co, Pittsburgh.

General construction. There are 1 or 2 storage tanks, which, with piping, etc, are carried on a frame mounted on 4 or 6 driving wheels. The cyls are usually simple, sometimes compound. The high-press air of the storage tanks passes into a small auxiliary tank, where it is reduced to proper working press, before going to the cyls.

Air pressure in storage tanks, 700 to 1 200 lb. Cyl press: simple engine, 125–150 lb; compound engine, 200–250 lb. Intermediate press for compound cyls, 50–60 lb. TANK CAPACITY, for hauls of 1 to 1.5 mile, 50–150 cu ft. For long hauls, it is better to increase press, rather than size of tanks.

Reheating (Art 16) restores heat lost in reducing press to that of the auxiliary tank; it is essential for compound cyls, the temp of exhaust from high-press cyl being far below freezing. Fig 63 shows the H. K. Porter Co's INTERHEATER for compound locomotives. Between the cyls is a shell filled with small tubes, through which the warm atmospheric air is drawn by the ejector action of the low-press exhaust. Nearly all the heat lost in the high-press cyl is thus restored, expanding the air about 36%. It is claimed that the use of the interheater effects a reduction of about 30% in

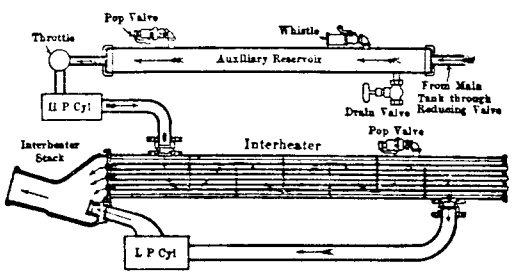


Fig 63. Diagram of Locomotive Cylinders and Interheater (H. K. Porter Co)

size of compressors and boilers, and in power costs, and of about 15% in first cost of installation; or an increase of about 30% in length of haul on 1 charge of air.

In gaseous mines a simple method of reheating is to inject into the auxiliary tank steam or hot water each time the locomotive is charged. In non-gaseous mines, a small oil or coke-burning furnace is used.

Table 69. Compressed-air Haulage Plants

Location	Locomotive wt, ton	Tanks: Capac, cu ft	Tanks: Air press, lb	Working press, lb	Cyls: Diam, in	Cyls: Stroke, in	Locos: Height Length Width, ft	Cars, wt: Empty, lb	Cars, wt: Load, lb	Cars in train	Max grade, %	Length round trip, ft	Charging time, sec
Buck Mt, Pa (a) ..	8	130	550	...	7	14	5.2×19×—	3400	7000	12	4.5	5100	...
Glen Lyon, Pa...	8	130	550	160	7	14	.....	2800	7000	12–20	2.8	8000 4200	...
Grass Val, Cal ...	....	30	500	...	....	....	4.3×5×2.5	....	2000	5	...	...	...
Vivian, W Va (b).	5	....	500	125	5	10	4.5×0.5×5.8	8500		6	2.5	9000	20
P & R Coal & Ir (c)	.....	.....	600	180	....	....	.....	3300	5500	15–38	0.8	5200	60
" (d)	.....	.....	600	180	....	....	.....	.....	.....	4–10	5.5	3200	...
"	11	....	600	200	....	....	6.5×14×6.3	9000		32	1.7	.....	...
Wilson Coll'y (e)..	...	160	600	125	9	14	.....	5850		30	1.0	9000	85
Butte, Mont (f)...	5	47	550	125	5	10	5×10.4×5	3450		6	0+	...	60
Anaconda, Mont .	21 13	218 132	750	150	12×18 9.5×14		.....	.....	.....	.....	...	1000 to 7000	...
Lead, S D (g)....	5	.....	.....	.....	.....	.....	5×10.5×3.3	.....	.....	.....	...	.....	...
Norway, Mich....	7	....	700	140	7	12	5.2×12×4.2	1800	1800	20	...	12000 to 14000	45

Notes: (a) 1 loco delivered 150 cars in 10 hr, formerly requiring 10 mules. Aver cost per ton-mile: by air, gross, 1.875¢; net, 3.77 ¢; by mule, gross, 3.94¢; net, 7.92¢. (b) Cost of locomotive, $1 800. Max speed, 10 to 12 miles per hr. Capac of main storage tank, 47 cu ft at 535 lb press. Press in pipe line, 735 lb. (c) See "Cost of Plant" (3). Cost for 180 days per year: daily operating cost, $14.69; fixed charges @ 10% and cost of steam power, $9 per day; cost per day per car for 666 cars, 3.6¢ (previous cost by mule, 5.1¢ per day per car). (d) Locos are 4-cyl compound, 5 and 8 by 12 in. (e) Pipe-line press, 700 lb; air reheated. Cost per gross ton-mile, 1.25¢. (f) 2 round trips per charge on cold air; 3 on reheated air. (g) Locos have detachable rear end, to permit loading on to a 9-ft cage.

Tractive force of compressed-air locomotives may be found by $T = (D^2 \times L \times 0.98\,P) \div d$: where T = tractive force, lb; D = diam of piston, in; L = stroke, in; P = initial press, lb; $0.98\,P$ = effective cyl press; d = diam driving wheels, in (3). For compound cyls, the effective cyl press is taken as $0.85\,P$, P being actually the difference between the initial press in high- and low-press cyls; and it may be assumed that there are either 2 low-press or 2 high-press cyls, as the same power is generated in both.

Table 70. Compound Compressed-air Locomotives (H. K. Porter Co)

Class	Cylinders, in: Diam, h-p	Cylinders, in: Diam, l-p	Cylinders, in: Stroke	Rigid wheel base, ft, in	Length over bumpers, ft, in	Extreme width outside of gage, in	Height, ft, in	Main tank capac, cu ft	Weight in working order, lb	Tractive force, lb	Weight lightest rail per yd, lb	Radius sharpest curve, ft (b)
B-P-O	4.5	9	10	2 9	9 c 12 6	12¼	(a)	20 60	7000 10000	1450	16	12
"	5.5	11	10	2 9	10 c 12 6	14¾	(a)	30 75	10000 13000	2200	16	12
"	6	12	12	3 0 4 0	12 c 15 6	15	(a)	60 104	14000 17000	3000	20	15
"	7	14	14	4 0	12 c 18 6	16½	(a)	60 120	18000 22000	4400	30	20
P-B	4.5	9	10	2 9	9 c 12 6	12¼	8 0	20 60	5000 10000	1450	16	12
"	5.5	11	10	2 9	10 c 12 6	14¾	8 6	30 75	10000 13000	2200	16	12
"	6	12	12	3 0	12 c 15 6	15	"	60 104	14000 17000	3000	25	15
"	7	14	14	4 0	12 6 18 6	16½	9 0	60 120	18000 22000	4400	30	20
B-PP-O	7	14	14	4 0	14 0 20 0	16½	5 0 5 10	97 160 (c)	20000 27000	4400	30	16
"	8.5	12&12	14	4 6	16 0 20 0	16½	"	114 210 (c)	28000 36000	6400	40	18
"	9.5	14&14	14	4 6	18 0 21 0	18	"	160 275 (c)	32000 42000	8000	45	20
"	10	14&14	14	5 0	20 0 23 0	18	5 5 5 10	160 290 (c)	43000 46000	9000	50	25
B-PP	8.5	17	16	5 6	14 0 18 0	16½	10 0	114 210 (d)	28000 36000	6400	40	30
"	9.5	19	18	5 6	18 0 21 0	18	11 0	160 290 (d)	32000 42000	7500	45	30
"	11	22	18	5 9	19 0 22 0	25¼	12 0	260 375 (d)	55000 60000	10000	55	40
"	13	26	24	6 6	10 0 24 0	29¼	"	"	69000 73000	14500	65	50
"	15	30	24	6 6	22 0 26 0	33	"	"	95000 100000	19500	80	50
C-PP	7	14	14	5 6	14 0 20 0	16½	5 0 5 10	97 160 (c)	20000 27000	4400	25	30
"	8.5	12&12	14	5 6	16 0 20 0	16½	"	114 210 (c)	28000 36000	6400	30	30
"	9.5	14&14	14	5 6	18 0 21 0	18	"	160 275 (c)	32000 42000	8000	35	30
"	10	14&14	14	5 6	20 0 23 0	18	"	160 290 (c)	43000 46000	9200	40	50

(a) Depends on gage. (b) Radius advised, 25–50% greater. (c) 2 tanks. (d) 2 or 3 tanks. Main tanks are built for press of 700 or 1 200 lb; auxiliary tank press for all, 250 lb. Tenders accompany locos, if space is limited; useful for long hauls.

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La traction à air comprimé, aux mines de Saint-Jean-de-Valériscle (Gard).

La traction à air comprimé a été installée aux mines de Saint-Jean-de-Valériscle, appartenant à la Compagnie des Mines de la Grand'Combe. Sa mise en service, à la fin de 1923, se justifie par l'éloignement du puits d'extraction du centre de gravité du roulage : elle excède 2000 mètres. M. Bernard a donné la description du matériel et de l'installation, dans la *Revue de l'Industrie minérale*, du 15 avril.

L'installation comprend deux compresseurs, l'un normalement en service, l'autre en réserve. La compression de l'air se fait en quatre relais : 3, 12, 50 et 165 kg. Le compresseur comprend deux cylindres, munis chacun d'un piston différentiel. A la vitesse normale de 150 t/mn, le compresseur aspire 9 m³ d'air à la pression atmosphérique. Quand la pression atteint dans les tuyauteries 165 kg, les soupapes d'aspiration des différents relais sont immobilisées dans leur position d'ouverture, le compresseur marche alors à vide.

Les locomotives portent cinq réservoirs d'une contenance totale de 1350 litres, dans lesquels l'air est emmagasiné à 150 kg/cm². A la sortie des réservoirs, l'air passe par un détendeur qui ramène la pression à 30 kg Il va ensuite dans un réservoir, dit « de travail », dans lequel l'air détendu est réchauffé par l'air de la galerie. La détente dans le moteur est à triple expansion : 30-15 kg, 15-5 kg, 5-1 kg. Entre chaque détente, l'air se réchauffe dans un réservoir de travail.

La tuyauterie est constituée par des tuyaux en acier de 30 mm de diamètre intérieur et 40 mm de diamètre extérieur.

La plus importante des installations de mine est le dépôt des locomotives. Constitué par une galerie en cul-de-sac de 30 mètres de longueur et de 4m 50 de largeur, il renferme les appareils précités et trois prises de chargement aménagées de façon à pouvoir charger les locomotives, quelle que soit leur position.

Le réseau comprend actuellement 3 950 mètres de galeries, dont 1 420 mètres à double voie.

Les convois sont au maximum de 50 berlines d'une contenance d'environ 550 litres. La vitesse moyenne est de 8 à 10 km/h.

Avant l'emploi de l'air comprimé, la traction se faisait par chevaux ; c'était, soit deux chevaux remorquant un convoi de 25 berlines, soit un cheval isolé remorquant 12 berlines. Il y avait 17 conducteurs et 23 chevaux.

Actuellement le personnel se compose de : 2 machinistes de compresseur ; 5 machinistes de locomotives ; 2 ajusteurs ; 3 aiguilleurs ; 12 hommes au total. La production a pu être augmentée de 30 %.

La mine possède 6 locomotives, dont 4 en service, 1 en réserve et 1 en nettoyage ou réparation.

La comparaison du prix de revient des deux systèmes de roulage est difficile à établir ; on peut estimer cependant qu'il est inférieur d'environ 30 % avec la traction à air comprimé.

Des mesures de la consommation d'air, par les locomotives, qui ont porté sur cinq jours de marche normale, ont permis d'établir : la consommation d'air par tonne kilométrique utile, qui est 2m³ 343 d'air à la pression atmosphérique, et la consommation d'air par tonne kilométrique brute, qui est de 1m³ 036.

On a pu, enfin, calculer le rendement de l'installation, c'est-à-dire depuis le moteur électrique jusqu'à la locomotive, en passant par le compresseur ; on a trouvé 0,13.

On conçoit que, par ce faible rendement et par le coût de l'installation, la traction à air comprimé soit onéreuse. Mais elle a le gros avantage, par rapport à la traction par chevaux, d'augmenter beaucoup le débit du roulage et, par suite, de donner la possibilité d'augmenter la production. Aux mines de Saint-Jean-de-Valériscle, on peut rouler, par heure, trois convois de 50 berlines sur 2km 500, soit 375 berlines-kilométriques, alors que dans les mêmes galeries, avec les chevaux, on ne pouvait dépasser 150 berlines-kilométriques à l'heure.

 p. 1339-1344

Die Grubenlokomotivbahnen in der Nachkriegzeit

Von Prof. Dr.-Ing. SPACKELER, Technische Hochschule Breslau

Entwicklung der Grubenlokomotiven unter der Bedingung höchster Leistung in Hauptstrecken, aber kleinster Abmessungen in Abbauen. Einzelheiten der Konstruktion von Fahrdraht-, Benzol- und Druckluftlokomotiven. Eingehendere Behandlung der Akkumulator- und der Diesellokomotive, sowie der Druckluftlokomotive mit Mehrzylindermotor, da hier grundlegende Veränderungen eingetreten sind.

Der Bergbau hat, soweit er in altbergmännischer Weise als Tiefbau betrieben wird — nur davon soll hier die Rede sein —, nicht die gleiche Mechanisierung durchgemacht wie manche andre Industrien, die zur Arbeit am laufenden Band übergehen konnten. Gleichwohl ist die Nachkriegsentwicklung unseres Bergbaues doch durch eine starke Steigerung der Förderung der einzelnen Schachtanlage gekennzeichnet. Zusammenlegung benachbarter Grubenfelder und Übernahme ihrer Förderung auf einen leistungsfähig ausgebauten Hauptförderschacht ist das Kennzeichen der Entwicklung der letzten Jahre, besonders im Steinkohlen- und Kalisalzbergbau.

Die Zusammenlegung des Bergwerkbetriebes führte zu einer Entwicklung der Lokomotive nach zwei entgegengesetzten Richtungen. Für die Hauptförderstrecken ergab sich eine starke Steigerung der Leistung, sowohl des Förderweges wie der Fördermenge, ohne daß aus bergmännischen Rücksichten die wichtigsten Abmessungen der Fördermittel verändert werden durften. Die Größe der Förderwagen und die Spurweite waren durch die Schächte, der Streckenquerschnitt durch den Gebirgsdruck, die Gleiskrümmung und damit der Achsstand durch die Eigenart der Lagerstätte festgelegt. Anderseits ermöglichte die größere Fördermenge des einzelnen Arbeitsortes eine mechanische Streckenförderung bis in die Abbaue hinein, wo bisher noch Handförderung geherrscht hatte. Damit ergaben sich zwar kleine Leistungen, aber auch unvermeidlich kleinste Abmessungen dieser Abbaulokomotiven. Die Ausnutzung einer solchen Lokomotive zwingt dazu, mehrere Abbauörter durch eine Lokomotive bedienen zu lassen. Dazu muß diese oft mehrmals in einer Schicht in Stapelschächten gehoben und gesenkt werden, so daß ihre Maße die eines gewöhnlichen Förderwagens nicht überschreiten dürfen. Daher muß die Entwicklung im folgenden nach den beiden verschiedenen Gesichtspunkten betrachtet werden, einmal nach der Forderung großer Leistung, und zum andern nach der Forderung kleinster Abmessungen[1]).

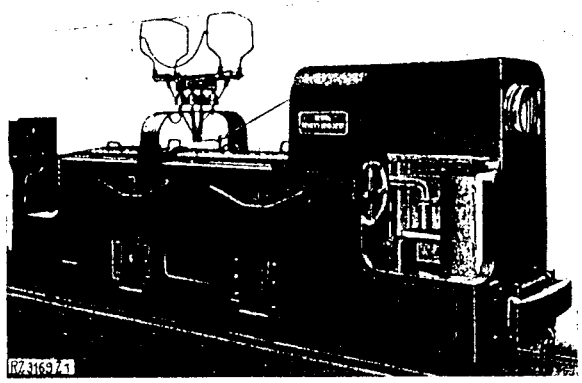


Abb. 1. Fahrdraht-Grubenlokomotive.
Siemens-Schuckertwerke, Berlin.

Oberleitungsbahnen

Von allen unter Tage in Betracht kommenden Lokomotivarten weist die Fahrdraht-Lokomotive die größte Betriebsicherheit und Leistungsfähigkeit auf. Leider stehen diesem Vorzug ein paar wichtige Untugenden gegenüber: Gefahr des Berührens des Fahrdrahtes, Funkengefahr in Schlagwettergruben, Streuströme, die bei der Schießarbeit zur Frühzündung der Sprengstoffe führen können, und Abhängigkeit vom Fahrdraht mit seinem teuren Einbau und sorgfältig zu überwachender Isolation. Diese Eigenschaften schließen die Fahrdrahtbahn für Abbaustrecken aus. Um so wichtiger ist sie für die Hauptstrecken geworden.

Die Frage der Stromart ist vorläufig zugunsten des Gleichstroms entschieden. Die weitaus verbreitetste Spannung der Fahrdrahtbahnen beträgt nur 220 V, wozu am Umformer eine Erzeugerspannung von höchstens 250 V vorhanden sein darf.

Die konstruktive Durchbildung der Gleichstromlokomotive war bereits in der Vorkriegzeit so sorgfältig und gut, daß der Aufbau im ganzen sich nicht mehr wesentlich verändert hat. Die beiden Hauptschlußmotoren, die nach Bedarf hinter- und nebeneinander geschaltet werden, sind möglichst tief im Rahmen des Fahrgestells untergebracht. Damit ist der Größe der Motoren durch Spurweite und Achsstand eine Grenze gezogen. Für die verbreitetste Spur von 600 mm sind jedoch die stärksten unter Tage gebrauchten Lokomotiven (für etwa 50 Vollwagen zu 1 t brutto bei 4 m/s) zu bauen.

An Verbesserungen der letzten Jahre verdient der allgemeine Übergang zu Kugel- oder Rollenlagern an den Motoren Erwähnung, nicht nur der Kraft- und Ölersparnis wegen, sondern vor allem, weil dabei eine bessere Abdichtung des Motors gegen Schmutz und Staub — ein sehr wichtiger Punkt — erreicht wird. Die wichtigste Neuerung am Fahrschalter dürfte eine Verriegelung sein, durch die das sofortige Umlegen des Schalters auf Gegenstrom verhütet wird; die Lösung dieser Verriegelung, die erst nach Ausschalten des Stromes möglich sein darf, erfordert soviel Zeit, daß schädliche Beanspruchungen des Motors verhütet werden. Schnell verbreitet hat sich eine Kurzschließvorrichtung, weil sie die sonst bergpolizeilich geforderte Signalanlage ersetzt: durch einen Handschalter kann zwischen Fahrdraht und Schiene ein Kurzschluß hergestellt werden. Dadurch treten die Höchststromauslöser in der Erzeugerstation in Tätigkeit; sollten sie versagen, z. B. bei zu großer Entfernung, so wird jedenfalls das Spannungsgefälle zwischen Fahrdraht und Schiene praktisch auf null herabgesetzt, so daß keine Gefahr bei Arbeiten an der Lokomotive besteht.

Viel Arbeit ist auf Versuche verwendet, die Funkenbildung zwischen Stromabnehmer und Fahrdraht, sowie zwischen Rad und Schiene zu verhüten. Die Bestrebungen gewannen besonders an Bedeutung, als im Jahre 1925 eine unglückliche Häufung von Schlagwetterexplosionen auftrat, die auf diese Funkenbildung zurückgeführt wurde. Der preußische Landtag nahm daraufhin gegen die Fahrdraht-Lokomotiven Stellung, und das preußische Grubensicherheitsamt verbot ihre Verwendung im ausziehenden Wetterstrom von Schlagwettergruben.

Trotz vieler Versuche hat man wohl eine Verminderung, nicht aber eine Verhütung der Funkenbildung erreicht. Die größere Bedeutung kommt den Funken am Fahrdraht zu, da die Schlagwetter sich unter der Firste sammeln. Meist verwendet man mindestens zwei parallel geschaltete Bügel solcher Konstruktion, daß auch bei stark wechselnder Höhenlage des Fahrdrahtes ein gleichmäßiges Andrücken des Bügels gewährleistet ist, was bei den Scherenstromabnehmern bis zu 1 m Höhenunterschied möglich ist. Auch ein glatter Fahrdraht hat sich als wichtig erwiesen. Ein geeignetes Bügelmetall,

[1]) Der letzte zusammenfassende Bericht befindet sich im Aufsatz von *Gunderloch*, „Glückauf" Bd. 58 (1922) S. 589.

das weicher als das Kupfer des Drahtes ist, aber kurze Funkendauer gewährleistet (hoher Siedepunkt des Metalls[2]), ist dafür von Bedeutung. Über Versuche, den Fahrdraht ständig zu schmieren, wird günstig geurteilt, wenn auch ein abschließender Bericht noch nicht vorliegt.

Eine Reihe von Unfällen hat die Notwendigkeit gezeigt, der Streckenausrüstung größere Aufmerksamkeit zuzuwenden[3]). Der Fahrdraht darf des Funkens wegen nicht durchhängen, darf aber auch bei Bewegungen des Ausbaues durch Gebirgsdruck nicht so gespannt werden, daß er reißt. Deshalb sind nachstellbare Drahthalter konstruiert. Vor allem aber ist eine einwandfreie Rückleitung des Stromes durch die Schienen zu gewährleisten, um vagabundierende Ströme zu verhüten. Schweißung der Schienen läßt sich aus bergmännischen Rücksichten selten durchführen (Verbot des Schweißens in Schlagwettergruben, Dehnbarkeit der Schienen bei Gebirgsbewegungen u. a. m.). Die beste Verbindung dürfte danach ein Kupferbügel sein, der — zum Schutze gegen Diebstahl — unter der Lasche in einer Nut liegt, mit den Schienen rostfrei und sicher verbunden und dehnbar ist.

Abb. 1 zeigt eine neuzeitliche Grubenlokomotive für Fahrdrahtbetrieb.

Akkumulator-Bahnen

Akkumulator-Lokomotiven haben für den Bergwerksbetrieb mancherlei Vorzüge: bei Kapselung der Motoren und Schalter sind sie schlagwettersicher; ihre Unabhängigkeit vom Fahrdraht macht sie für enge und druckhafte Strecken geeignet; der Motor ist der gleiche wie bei der Fahrdrahtlokomotive: ein Gleichstrom-Hauptschlußmotor mit hohem Anzugmoment, großer gelegentlicher Überlastbarkeit und ausgezeichneter Manövrierfähigkeit. Wenn die Akkumulator-Lokomotiven gleichwohl lange nur geringe Anwendung fanden, so lag das teils an der Empfindlichkeit und den hohen Anschaffungskosten der Akkumulatoren, teils an der geringen Leistung.

Voraussetzung für eine Entwicklung der Akkumulator-Lokomotiven war deshalb eine Verbesserung der Elemente durch Hebung von Widerstandkraft und Kapazität. Indem man die alten Holzkästen durch eiserne Tröge mit einer Gummieinlage ersetzte, gelang es, die Kapazität bei gleichem Raum bis über 30 vH zu steigern. Jetzt ist es gelungen, durch Bau der Panzerplattenelemente an Stelle der älteren Großoberflächenelemente die Kapazität erheblich weiter zu verbessern, leider auf Kosten der Widerstandfähigkeit und des Herstellungspreises. Am größten ist die Kapazität der Gitterplattenbatterien, die aber eine so sorgfältige Wartung erfordern, daß sie im Grubenbetrieb nur im Notfalle verwendet werden. Den größten Fortschritt dürfte die Erfindung des Edisonelementes in seiner Ausführung mit Nickel- und Kadmiumplatten gebracht haben. Die älteren Nickel- und Eisenzellen entwickeln bei der Ladung ziemlich viel Gas, gasen auch nach der Ladung noch eine gewisse Zeit nach. Diese unangenehme, in Schlagwettergruben unzulässige Eigenschaft wird durch Einführung des Kadmiums an Stelle der Eisenmasse in die negative Platte vermieden.

Die Entwicklung der Akkumulatoren und ihre Eignung für den Lokomotivbetrieb wird durch die folgende nach Angaben der Accumulatoren-Fabrik, A.-G., Berlin, aufgestellte, auf 5stündige Endladezeit berechnete Zahlentafel 1 gekennzeichnet.

Während Panzerplatten- und Edisonzellen für eine volle Schicht ausreichen, erreichen Oberflächenbatterien bei üblicher Beanspruchung nur eine zwei- bis dreistündige Entladezeit, so daß sie einmal in der Schicht auszuwechseln sind. Großoberflächenbatterien brauchen eine drei- bis vierstündige, Panzerplatten- und Edisonbatterien eine etwa siebenstündige Ladezeit. Bei einschichtigem Betrieb reichen daher zwei Großoberflächenbatterien oder eine Panzerplatten- oder eine Edisonbatterie je Lokomotive aus. Läuft die Lokomotive in

[2]) Safety in mines Research Board, Bericht Nr. 20, London 1926, und „Elektrizität im Bergbau" Bd. 2 (1927) S. 1.
[3]) *Ullmann*, „Elektrizität im Bergbau" Bd. 1 (1926) S. 21.

Zahlentafel 1
Vergleichzahlen der Elementarten

	für 1 kWh erforderlich		
	Gewicht kg	Raum dm³	Kosten ℳ
Großoberflächenelemente .	100	33	220
Gitterplattenelemente . . .	40	14	120
Panzerplattenelemente . .	60	20	200
Edisonzellen (Nickel-Kadmium-Platten)	40	15	480

zwei Schichten, so sind drei Großoberflächen- oder zwei Panzerplatten- oder Edisonbatterien zu beschaffen. Leider steht der hohe Preis der Einführung der Edison-Akkumulatoren hinderlich im Wege. Ihm steht aber ein billigerer Betrieb durch die größere Unempfindlichkeit gegen Stoß und Überanstrengung und längere Lebensdauer gegenüber.

Die Entwicklung der Akkumulatoren ermöglichte die Ausgestaltung der Lokomotiven nach beiden Richtungen durch Aufspeicherung größerer Energiemengen für höhere Leistungen in Hauptstrecken, aber auch durch Herabsetzung der Batteriegröße für Abbaulokomotiven.

Für Hauptstrecken werden Lokomotiven mit Motoren bis zu 50 kW Stundenleistung gebaut. Sie können unter normalen Verhältnissen etwa 50 volle Förderwagen von 1 t brutto mit 3 m/s zum Schacht bewegen und die leeren zurückbringen. Die Bleibatterien bestehen aus etwa 80 Elementen, so daß die Entladespannung 150 V beträgt, der Ladestrom aber einem Normalnetz mit 220 V entnommen werden kann. Bei alkalischen Elementen, die je Element nur 1,7 bis 1,8 V Lade- und 1,2 V mittlere Entladespannung haben, wird die Zahl entsprechend höher gewählt.

Für die Abbaulokomotiven genügen meist Stundenleistungen des Motors von 4 bis 5 kW, da die Geschwindigkeit in den druckhaften Abbaustrecken doch niedrig (1 bis 1,5 m/s) gehalten werden muß und Zuglängen von mehr als 10 Wagen selten sind. Anderseits ist die Größe der Batterie beschränkt. Die Zellenzahl wird daher so herabgesetzt, daß je nach der geforderten Leistung Entladespannungen von 50 bis 80 V entstehen.

In vielen Fällen dürfen die Abmessungen der Abbaulokomotiven nicht über diejenigen eines einfachen Förderwagens hinausgehen, um sie auf dem Förderkorb der Stapelschächte unterbringen zu können. Das wird mittels Zerlegung durch einfaches Lösen des Führersitzes einschließlich Schaltwalze oder durch Hochklappen des Sitzes erreicht. Das Gesamtgewicht solcher Lokomotiven liegt zwischen 2,5 und 3 t bei Edison-, zwischen 3 und 4 t bei Panzerplattenelementen.

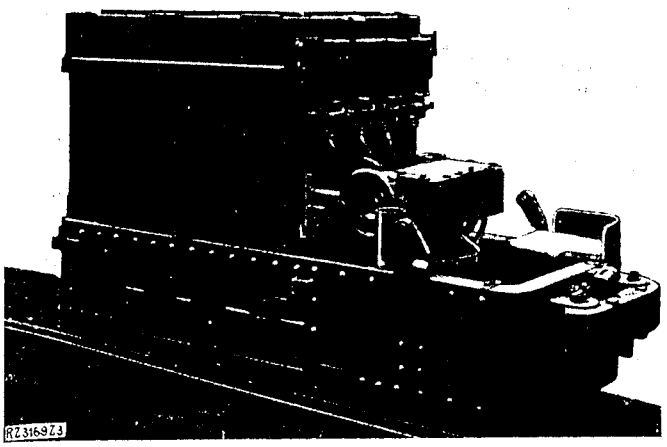
Während man bei Fahrdraht-Lokomotiven die Zugkraft durch Hinter- oder Nebeneinanderschalten der zwei Motoren verändert, läßt sich bei Akkumulator-Lokomotiven das gleiche einfacher durch entsprechende Schaltung der Zellen erreichen. Sie brauchen daher nur einen Motor, ein Vorteil, den man bei Abbaulokomotiven ausnutzt. Im übrigen entspricht ihre Ausgestaltung derjenigen der Fahrdraht-Lokomotive.

Zwecks Schlagwetterschutz werden Motor und Schalter in gleicher Weise wie bei den Fahrdraht-Lokomotiven durch eine vollständige Kapselung gesichert, die auf einen Innendruck von mindestens 8 at bemessen sein muß. Für die Batterie kommt bei ihrer Größe und in Anbetracht einer möglichen Gasentwickelung bei der Ladung das gleiche nicht in Frage. Die Batterie wird daher durch Plattenschutz gesichert.

In Abb. 2 und 3 sind zwei Akkumulatoren-Lokomotiven, die eine für Hauptstrecken, die andre für Abbaustrecken, nebeneinandergestellt. Man erkennt die ganz andern Bedingungen, die die Form der Lokomotiven für Abbaustrecken bestimmen.

Lokomotiven für flüssige Brennstoffe

Lokomotiven mit Benzolmotor verdanken den Bedürfnissen des Bergbaues ihre Entstehung, die jetzt über 30 Jahre zurückliegt. Unter engem Zusammenarbeiten



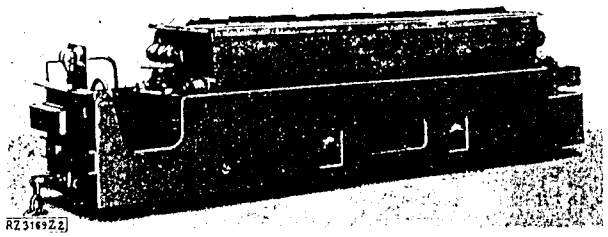


Abb. 2. Akkumulator-Lokomotive für Hauptstrecken.
AEG, Berlin.

Abb. 3
Abbau-Akkumulator-Lokomotive mit hochgeklapptem Führersitz für Beförderung durch Stapelschächte.
„Bergbau", Gesellschaft für betriebstechnische Neuerungen m. b. H. Dortmund.

der Erbauer mit den Organen des Bergbaues ist die Weiterentwicklung durchgeführt worden. Nachdem in der berggewerkschaftlichen Versuchsstrecke in Derne (Westfalen) die wesentlichen Sicherheitsmaßnahmen an den Lokomotiven und ihrem Zubehör (Brennstoffördergerät, Umfüllanlage usw.) durch Versuche festgelegt und die Lokomotiven unter zahlreichen bergpolizeilichen Vorschriften in Schlagwettergruben zugelassen waren, standen Richtlinien für die Hauptteile fest. Die Entwicklung der Nachkriegzeit beschränkt sich daher auf die Verbesserung von Einzelteilen der Lokomotive, während alle Vorrichtungen, die dem Umgang mit dem Brennstoff dienen, ziemlich unverändert geblieben sind. Die naheliegende Vermutung, daß die lebhafte technische Entwicklung des Kraftwagens auch der Benzollokomotive zugutegekommen sei, ist irrig. Versuche mit leichten Motorkonstruktionen auf Grubenlokomotiven führten z. B. dahin, daß man das Dienstgewicht der letzteren künstlich erhöhen mußte. Dabei ist stabile Bauart wichtiger als die meisten vom Kraftwagen geforderten Eigenschaften.

Als Motor herrscht bei kleinen Lokomotiven noch heute der liegende Einzylinder-Viertaktmotor vor, während man bei großen Leistungen zu stehenden Mehrzylindermotoren übergegangen ist. Nur die Rheiner Maschinenfabrik Windhoff baut sämtliche Grubenlokomotiven mit stehenden Mehrzylindermotoren, die zwar eine höhere Umlaufzahl bedingen, aber das sonst unvermeidliche schwere Schwungrad ersparen.

An Vergasung und Auspuff sind keine grundlegenden Neuerungen zu verzeichnen. Zweckmäßig ist die Deutzer Anordnung, wonach die Brennstoffleitung zum Vergaser und die Wasserleitung zur Brause im Auspuffrohr nur gemeinsam geöffnet und geschlossen werden können. Es kann sonst bei Stillstand Wasser ins Auspuffrohr gelangen, das beim Wiederingangsetzen in den Zylinder gesogen wird, oder es können die heißen Gase auspuffen und die Grubenwetter verschlechtern.

Bei den älteren Lokomotivkonstruktionen lag der Lokomotivbehälter meist über dem Kurbelgetriebe. Beschädigung an ihm beim Bruch einer Pleuelstange und Ausfließen des Benzols, das dann meist durch Funkenbildung in Brand geriet, führten zu der Vorschrift, den Brennstoffbehälter durch eine dicke eingelegte Eisenplatte zu sichern. Bei neueren Lokomotiven ist der Behälter so gelegt, daß er vom Getriebe nicht getroffen werden kann. Umlaufschmierung ist allgemein durchgeführt. Zur Kühlung des Zylinders benutzt man bei liegenden Motoren vorherrschend Verdampfungskühlung. Sie hat den Vorteil, den für den Grubenbetrieb reichlich empfindlichen Wasserrückkühler auszuschalten, und hat sich als ausreichend erwiesen.

Eine Verbesserung an der Zündvorrichtung ist von der Motorenfabrik Deutz A.-G., Köln-Deutz, zuerst angewendet. Bei voller Umlaufzahl muß der Zündfunke kurz vor Beendigung des Verdichtungshubes überspringen, damit die Explosionswirkung gerade bei Beginn des Arbeitshubes einsetzt (Frühzündung). Bei niedriger Umlaufzahl ist die Zeit für den gleichen Kolbenweg zu lang, so daß Spätzündung notwendig ist, um einen Rückschlag des Kolbens zu vermeiden. Mehrfach sind Lokomotivführer, die die Anlaßkurbel drehten, schwer verletzt worden, wenn sie die Umschaltung auf Spätzündung vergessen hatten. Die kleine Zünddynamo ist deshalb mit einem Regler versehen, der selbsttätig bei niedriger Umlaufzahl auf Spätzündung stellt und bei Erreichen der vollen Geschwindigkeit auf Frühzündung umschaltet.

Hält die Lokomotive ohne Stillsetzen des Motors an schlecht bewetterter Stelle, so sind Vergiftungen möglich. Das Bestreben geht deshalb dahin, das Anlassen mechanisch, durch Druckluft oder durch elektrischen Strom, zu bewirken. Leider sind die bisher auf dem Markt befindlichen Bauarten elektrischer Anlasser nicht schlagwettersicher ausgeführt, so daß man im Steinkohlenbergbau auf Druckluft angewiesen ist.

Sehr verschieden haben die Firmen die Aufgabe gelöst, trotz der federnden Verbindung zwischen Lokomotivrahmen und Radsatz die Bewegung der Kurbel auf die Achsen zu übertragen. Die Ruhrthaler Maschinenfabrik verwendet bei kleineren Lokomotiv-Bauarten die früher auch von andern Firmen unmittelbar benutzte Galische Kette. Deutz läßt das Zahnradvorgelege auf die Achsen wirken, wobei der durch stoßartige Beanspruchung bedingte Verschleiß durch Einbetten des ganzen Getriebes in ein Ölbad ausreichend vermindert wird. Die Rheiner Maschinenfabrik baut ihre Lokomotiven mit einer Blindwelle *a*, Abb. 4, die im Rahmen der Lokomotiven fest verlagert ist und vom Motorgetriebe gedreht wird. Blindwelle und Laufräder sind durch eine Kurbel und eine Kuppelstange *b* miteinander verbunden, in die zwischen Blindwelle und erstes Rad ein senkrecht wirkendes Gelenk *c* eingeschaltet ist. Damit ist Stoßfreiheit des Getriebes bei Bewegung der Blattfedern zwischen Achsen und Rahmen gesichert.

Um einen Überblick über die Größe der gebauten Benzollokomotiven zu geben, sei erwähnt, daß Deutz drei Bauarten von 3900, 5100 und 6300 kg Dienstgewicht mit 15, 20 und 25 PS Motorleistung baut. Sie sind imstande, bei guter Bahn und Kugellager-Radsätzen 40 bis 50 Grubenwagen (1 t brutto) mit Geschwindigkeiten bis zu

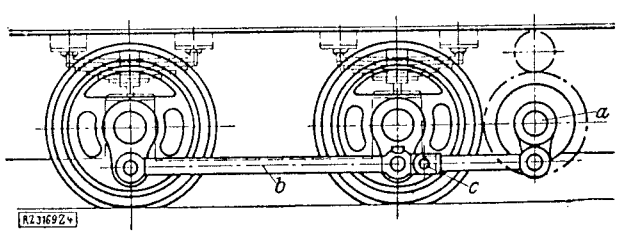


Abb. 4
Blindwellenantrieb für Grubenlokomotiven für flüssige Brennstoffe.
Rheiner Maschinenfabrik Windhoff.
a Blindwelle *b* Kuppelstange *c* Gelenk

1,5, 2 und 2,5 m/s zu ziehen. Dabei ist der Motor allerdings nur wenig überlastbar; die Lokomotiven müssen deshalb langsam anfahren.

Die Benzollokomotiven haben für den Grubenbetrieb eine Reihe vorteilhafter Eigenschaften. Vor allem ist, da der Brennstoffvorrat für eine Schicht mitgenommen werden kann und nur das verdampfte Kühlwasser nach etwa 2 h zu ersetzen ist, ihr Fahrbereich für den Grubenbetrieb praktisch unbeschränkt. Bei der notwendigen Sorgfalt in der Unterhaltung der Schutzvorrichtungen können sie auch als schlagwettersicher gelten. Alle Vorschriften haben dagegen nicht ausgereicht, um Benzolbrände zu verhüten, die von Zeit zu Zeit schwere Unfälle herbeigeführt haben. Benzolbrände sind im Grubenbetriebe deshalb so gefährlich, weil stets Wetterzug vorhanden ist, der die Verbrennung unterhält, die Brandschwaden aber in andre Baue und an andre Arbeitsplätze führt. Dabei entwickelt das heiße Benzol soviel Dämpfe im Überschuß, daß dadurch ein Zerfall der Kohlenwasserstoffe eintritt und unverbrannte glühende Kohlenstoffteilchen die Reduktion von CO_2 zu CO bewirken. Einem Benzolbrand in bewetterten Strecken steht man bisher machtlos gegenüber, um so mehr, als auch der hier zweckmäßigste Handfeuerlöscher, der Tetralöscher, wegen der Phosgengefahr in mehreren Bergbaubezirken verboten ist. Aus diesen Gründen stand die preußische Bergbehörde in der Nachkriegzeit den Benzollokomotiven nicht sympathisch gegenüber. Ihr Betrieb wurde vielfach erschwert oder unmöglich gemacht.

Es lag nahe, daß sich die Augen der Erbauer unter diesen Umständen auf den

Dieselmotor

richteten. Die Verschlechterung der Wetter durch seine Auspuffgase haben die Einführung dieses Motors lange verhindert. Heute hat man sich überzeugt, daß dieses Bedenken übertrieben war. Bei der hohen Kompression im Zylinder des Dieselmotors (35 at bei rd. 700°) verläuft die Verbrennung so vollständig, daß die Gefahr der CO-Bildung bei richtiger Einstellung des Motors geringer als beim Benzolmotor ist. Den unangenehmen Geruch hat man durch Einspritzen von Wasser in das Auspuffrohr zwar nicht beseitigt, aber erträglich gemacht. Vor allem hat man den Vorzug der Gefahrlosigkeit des Brennstoffes. Man kann ein so schweres Roh-, Gas- oder Teeröl verwenden, daß es unter normal vorkommenden Zündungsbedingungen (Berührung mit Streichholz, Grubenlampe, Reibungsfunken usw.) nicht in Brand gerät, daß vielmehr die hohen Drücke und Temperaturen des Dieselmotors zur Verbrennung erforderlich sind.

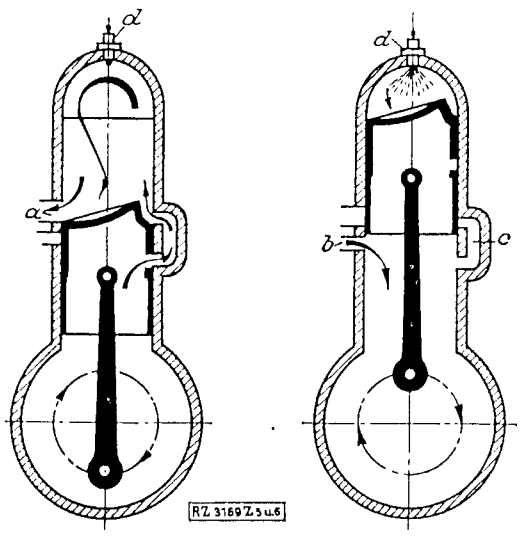


Abb. 5 und 6
Benutzung der eingekapselten Kurbel als Luftverdichter beim Zweitaktmotor.
Ruhrtaler Maschinenfabrik Schwarz & Dyckerhoff G. m. b. H., Mülheim-Ruhr.
a Ausströmöffnung *b* Luftansaugöffnung
c Lufteinblaskanal *d* Öleinblasventil

Die Ungleichförmigkeit des Viertakt-Dieselmotors liegt infolge der höheren Verdichtung bedeutend über der des Benzolmotors. Zweitaktmotoren bedürfen bekanntlich einer Druckluftspülung des Zylinders, von der man bisher eine unvollkommene Wirkung und daher CO-Bildung befürchtete. Für Grubenlokomotiven hat man sie daher bisher nicht benutzt. Die Ruhrthaler Maschinenfabrik beabsichtigt jetzt jedoch, auf Grund der umfangreichen an Feldbahnmotoren gemachten Beobachtungen die Zweitaktmotoren auch unter Tage zu versuchen, da sich die Befürchtungen als gegenstandlos erwiesen haben sollen. Eine besondere Luftpumpe für die Zylinderspülung wird dabei dadurch vermieden, daß die Kurbel infolge Kapselung zugleich als Luftverdichter dient, Abb. 5 und 6. Vorläufig herrscht im Grubenbetriebe der Viertaktmotor.

Deutz verwendet bei den Grubenlokomotiven bis 20 PS den liegenden Einzylindermotor, bei größeren Lokomotiven aber ebenso wie die übrigen Firmen stehende Mehrzylindermotoren. Aufgabe des Konstrukteurs ist es, die Lokomotive trotz dieser stehenden Zylinder so zu bauen, daß die Höhe möglichst wenig über die der Benzollokomotiven mit einem Zylinder hinausgeht. Zu diesem Zweck verzichten die Firmen z. T. auf Verdampfungskühlung und bauen eine Umlaufpumpe mit Rückkühler ein.

Als Motoren werden kompressorlose Bauarten verwendet. Während bei den normalen Dieselmotoren die Zerstäubung und gleichmäßige Verteilung des flüssig eingeblasenen Brennstoffes dadurch erfolgt, daß man den letzteren mittels Druckluft von etwa 70 at Überdruck in den Zylinder hineinschleudert, wird hier die Verteilung allein durch die Form der Einspritzdüse sowie des Zylinderdeckels und -kolbens erreicht[4]). Eine Zündvorrichtung kommt nicht in Frage. Das Brennstoffgemisch wird vielmehr durch Selbstzündung infolge der hohen Temperatur verbrannt, die die Luft im Kolben durch die Verdichtung auf etwa 35 at erreicht. An Hilfseinrichtung ist daher nur die Brennstoffpumpe erforderlich, die allerdings auf etwa 10 at drücken muß, um das Öl mit der notwendigen Geschwindigkeit in die auf 35 at verdichtete Luft einzublasen. Für die Unfallsicherheit ist dieser Vorgang wichtig. Denn dadurch wird erreicht, daß sich das brennbare Gemisch erst bei Beginn der Verbrennung bildet, wenn durch Druck und Temperatur der Luft im Zylinder eine vollständige Verbrennung gewährleistet ist.

Die übrigen Konstruktionsteile sind denen der Benzollokomotive, die auf Grund langjähriger Erfahrungen gestaltet sind, weitgehend nachgebildet. Die Umlaufzahl kann beim Dieselmotor nur durch eine Gemischänderung geregelt werden in der Weise, daß der Brennstoffdüse für jeden Hub eine vom Regler eingestellte Menge von Öl zugeführt wird. Verminderung der Luftzufuhr würde sofort bewirken, daß Zündungsdruck und -temperatur nicht erreicht würden. Die Lokomotiven haben meist zwei Geschwindigkeitstufen, bei mittleren Lokomotivgrößen etwa 1 bis 1,5 und 2 bis 3 m/s, und man kann während der Fahrt ziemlich alle dazwischenliegenden Geschwindigkeiten durch Beeinflussung des Reglers einstellen.

Schwieriger als beim Benzolmotor ist das Anlassen. Das Ankurbeln mit der Hand ist in Anbetracht der notwendigen Verdichtung der Zylinderluft auf 35 at ausgeschlossen. Als Antriebmittel kann man Druckluft verwenden, wozu ein Teil der Explosionsgase durch ein Ladeventil in eine auf 60 at geprüfte Druckluftflasche geleitet wird. Um das Anspringen beim Übergang von Druckluft auf Ölantrieb zu sichern, ist ein großer Energievorrat im Schwungrad erforderlich. Die Ruhrtaler Maschinenfabrik versieht außerdem ihre Motoren mit einer elektrischen Zündung, die nur bei den ersten Kurbeldrehungen eingeschaltet ist und ihren Strom einem Akkumulator entnimmt.

Die Bedeutung der Diesellokomotive für den Grubenbetrieb liegt nicht nur darin, daß die größte Ge-

[4]) Beschreibung des Deutzer Motors z. B. bei *Hoffmann*, Bergwerksmaschinen; Berlin 1926; S. 323.

Abb. 7
Gruben-Diesellokomotive.
Die seitlichen Bleche sind des Einblicks wegen entfernt.
Ruhrthaler Maschinenfabrik Schwarz & Dyckerhoff G. m. b. H. Mülheim-Ruhr

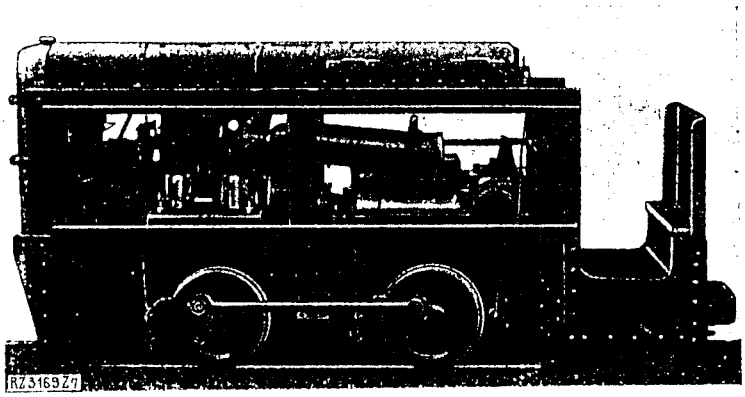
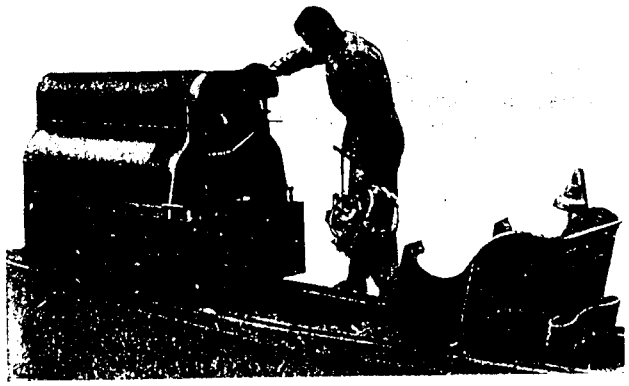


Abb. 8 (unten)
Druckluft-Abbaulokomotive mit abgenommenem Führersitz und Motor.
Berliner Maschinenbau A.-G., vormals Schwartzkopff, Berlin.



fahrenquelle, der Brand des Brennstoffs außerhalb des Motors, so gut wie beseitigt ist, sondern auch in ihrer Wirtschaftlichkeit. Geeignetes Schweröl mit 10 000 kcal/kg dürfte einem Dauerabnehmer nicht mehr als 15 ₰/kg kosten. Bei den gängigen Lokomotivgrößen kann man mit einem Verbrauch an Brennstoff von 200 bis 250 g/PSh rechnen, woraus sich für eine 20 PS-Lokomotive ein Verbrauch von 2 bis 3 kg/h und Brennstoffkosten von nur 30 bis 45 ₰/h ergeben. Brennstoffnachfüllung ist während der Schicht nicht erforderlich, nur das Kühlwasser muß ergänzt oder besser ersetzt werden. Deutz hat bisher vier Diesellokomotiven für Bergwerkzwecke herausgebracht, Zahlentafel 2.

Zahlentafel 2
Diesellokomotiven der Deutzer Motorenfabrik A.-G., Köln-Deutz.

Dienstgewicht . . . . . t	3,9	5,15	6,3	8
Motorleistung, normal . . PS	11	15	20	40
Höchstleistung . . . . „	12	16	22	44
Länge . . . . . mm	3500	3975	4155	4700
Höhe . . . . . „	1315	1480	1668	1590
Breite . . . . . „	785	815	885	860
Bauart	liegende Einzylindermaschine			4 Zyl. stehend

Die Ruhrthaler Maschinenfabrik hat bisher zwei größere Einheiten von 30 und von 60 PS, überlastbar bis 33 und 70 PS gebaut. Die großen Lokomotiv-Bauarten beider Firmen kommen auf Geschwindigkeiten bis zu 5 m/s, so daß sie an Leistungsfähigkeit selbst den Fahrdraht-Lokomotiven gewachsen sind. Es ist daher ein heftiger Wettstreit zwischen Diesel- und Fahrdraht-Lokomotive zu erwarten. Der ersteren kommt dabei zustatten, daß die Bergbehörde die Fahrdraht-Lokomotive im ausziehenden Wetterstrom von Schlagwettergruben verboten hat, so daß z. Z. vorhandene Anlagen nur noch befristet laufen. Die Diesel-Lokomotive dürfte die größte Aussicht haben, diese Erbschaft anzutreten. Abb. 7 zeigt eine Diesellokomotive der Ruhrthaler Maschinenfabrik

Druckluft-Lokomotiven

Auch die Druckluft-Lokomotiven waren infolge der Einfachheit ihres Grundgedankens und ihres Aufbaues bereits bei Kriegsbeginn soweit durchkonstruiert, daß ihre Bauweise sich in der Nachkriegszeit wenig veränderte, bis durch die Einführung der Abbaulokomotiven ganz neue Aufgaben hervortraten. Der Grundgedanke der Verwendung hochgespannter Druckluft, von der ein Vorrat in Stahlflaschen mitgeführt wird, ist wirtschaftlich in der Weise ausführbar, daß ein großer Teil der Energieverluste bei der Verdichtung durch Zwischenerwärmer zwischen den einzelnen Dehnungsstufen der Lokomotive kostenlos zurückgewonnen wird. Die Vorratsluft wird zunächst durch ein Druckminderventil auf einen gleichbleibenden Arbeitsdruck gebracht und in einem Zwischenwärmer, dem Arbeitsbehälter, annähernd wieder auf Umgebungstemperatur erwärmt. Erst danach folgt die Zuführung in die Arbeitzylinder, wobei zwischen die Expansionsstufen wiederum Zwischenwärmer eingeschaltet sind. Voraussetzung für die Verwendung von Druckluft-Lokomotiven ist daher die Möglichkeit, die für die Zwischenwärmer notwendigen Wärmemengen der umgebenden Luft entziehen zu können. Die Lokomotiven sind auf Strecken mit gleichmäßig warmen Wettern beschränkt, eine Voraussetzung, die im deutschen Steinkohlenbergbau im allgemeinen erfüllt ist. Da die Druckluft-Lokomotiven die größte Schlagwettersicherheit aller bekannten Lokomotivarten aufweisen, und da sie die Wetter durch ihre Kühlwirkung verbessern, ist die Druckluft-Lokomotive ein besonders geeignetes Fördermittel für unsere tiefen und schlagwetterreichen Steinkohlengruben geworden. Für Stollenbetriebe und wenig tiefe Schachtanlagen, bei denen die Lokomotiven in Wettern stark wechselnder Temperatur fahren, ist für die Erwärmung in den Zwischenwärmern eine besondere, meist mit Koks beschickte Feuerung notwendig.

Umstritten war lange Zeit die Frage, ob eine zweifache oder dreifache Dehnung der Druckluft im Motor der Lokomotive besser sei. Die Berliner Maschinenbau-A.-G. vormals L. Schwartzkopff, Berlin, läßt den Luftdruck seit langem auf 25 at im Arbeitsbehälter vermindern, um ihn dann dreistufig arbeiten zu lassen. Die übrigen Firmen begannen mit einem Arbeitsdruck von 15 bis 18 at und begnügten sich mit zweistufiger Expansion. Für diese Konstruktion führten sie neben der einfachen Bauweise an, daß bei dem häufigen Anfahren der Lokomotiven, wobei oft Frischluft in den Niederdruckzylinder eingelassen werden muß, der Vorteil der besseren Energieausnutzung bei dreistufiger Dehnung zu wenig zur Geltung komme. In welchem Sinne diese Frage heute gelöst erscheint, zeigt der Herstellungsplan der Demag, A.-G., Duisburg, die für lange Strecken eine Lokomotive mit dreifacher Dehnung baut, während sie für kurze Strecken und Verschiebezwecke ihre zweistufige Bauart empfiehlt. Mit der ersteren soll man bei gleichem Luftvorrat eine um 20 vH längere Strecke befahren können.

An wirklichen Verbesserungen der gebräuchlichen Lokomotivbauarten sind in der Nachkriegzeit nur zwei

erwähnenswert. Wirtschaftlich am wichtigsten ist die Erhöhung des Luftdruckes, der am Kompressor vor dem Kriege 100 at betrug, dann auf 150 und sehr bald auf 200 at gesteigert wurde. Neuerdings hat die Demag Lokomotiven für 225 at Fülldruck gebaut. Erhöhte Aufmerksamkeit ist der Wasserabscheidung zugewandt, da durch Wasser in den Druckluftflaschen Anfressungen der Innenwand festgestellt sind[5]). Die Flaschen werden daher mit einem Schauloch von etwa 50 mm Dmr. und mit einem Wasserablaßhahn an der tiefsten Stelle jeder Flasche gebaut.

Bei ausreichendem Streckenquerschnitt kommt man bis auf einen Inhalt der Flaschen von 1400 l. Bei einer Füllung von 150 at reicht dieser aus, einen Wirkungskreis von 3 km Halbmesser mit Zügen von etwa 40 gewöhnlichen Förderwagen zu beherrschen. Das entspricht einem Aufwand von rd. 1 m³ angesogener Luft, bezogen auf 1 Brutto-tkm. Bei kürzeren Strecken mit mehr Anfahrarbeit erhöht sich dieser Aufwand entsprechend. Als weitere übliche Angaben neuzeitlicher Druckluft-Lokomotiven können gelten: Gewicht 6,5 bis 7,5 t, Zugkraft 500 kg, durch Frischluft im Niederdruckzylinder beim Anfahren auf mindestens 1000 kg zu erhöhen, Dauerleistung 18 PS, Geschwindigkeit 3 m/s. Da der Querschnitt der Lokomotive durch die Strecken begrenzt ist, muß der Vorratsraum durch Länge der Lokomotive erreicht werden (bis über 4 m).

Der Vorzug der unbedingten Schlagwettersicherheit läßt die Druckluft-Lokomotive besonders geeignet erscheinen, als Abbaulokomotive im unmittelbaren Anschluß an die Gewinnungsorte der Kohle verwendet zu werden. In den letzten Jahren sind daher eine Reihe solcher Lokomotivbauarten unter besonderem Namen, z. B. Troll (Bergbau G. m. b. H., Dortmund), Grubenfloh (Schwartzkopff), Grubenzwerg (Demag) u. a. auf den Markt gekommen. Solche Lokomotiven dürfen die Größe eines Förderwagens nicht überschreiten oder sie müssen wenigstens in einfacher Weise in zwei Teile solchen Höchstmaßes zerlegt werden können. Kleine Maße sind aber gerade bei Druckluft-Lokomotiven schwer einzuhalten, weil die Vorratsflaschen einen bestimmten Raum verlangen. Ausgeschlossen ist es, den Energievorrat für eine ganze oder wenigstens für eine halbe Schicht bei sich zu führen. Eine mehrfache Füllung während einer Schicht ist notwendig. Es bedarf also der Verlegung der Rohre für hochgespannte Druckluft bis in die Nähe der Abbaue. Darin dürfte ein Haupthindernis für die Einführung dieser Lokomotiven liegen. Trotzdem zwingt das geringe Speichervermögen zu sparsamer Verwendung des Luftvorrates. Durch Mehrfachexpansion ist dieses Ziel nicht zu erreichen, da deren Vorteile durch Verluste bei dem häufigen Anfahren verlorengehen. Die Zwischenwärmer erfordern Platz, der hier mit Rücksicht auf den Luftvorrat besonders kostbar ist. Da sich zudem der hohe Ungleichförmigkeitsgrad des Motors auf den schlecht verlegten Schienen der Abbaustrecken besonders nachteilig geltend macht, sind einzelne Firmen von der sonst üblichen Anordnung des Motors abgegangen und zu neuen Konstruktionen gekommen, die den schlechten Schienen, den kurzen Strecken und dem häufigen Anfahren Rechnung tragen sollen.

Die Maschinenfabrik Jung, Jungenthal (Vertrieb durch Bergbau G. m. b. H., Dortmund), benutzt einen einfach wirkenden Vierzylindermotor, der bei 25 at Arbeitsdruck das gesamte Druckgefälle ohne Zwischenstufen im Gleichstromverfahren ausnutzt. Die vier Zylinder sind um 90° gegeneinander versetzt. Die Luft tritt an der Deckelseite des Zylinders durch eine Ventilsteuerung ein, um an der entgegengesetzten Seite durch Schlitze auszupuffen. Ein Ausdrücken der Luft durch den Kolben findet nicht statt, so daß der verbleibende Luftrest im Zylinder verdichtet und erwärmt wird. Die aus dem Arbeitsbehälter eintretende Druckluft mischt sich mit dieser erwärmten Luft. Dadurch wird eine Vereisung des Zylinders vermieden, obgleich im Auspuff Temperaturen von −70° gemessen sind. Als Vorteile dieses Motors, die dem Verzicht auf die Rückgewinnung von Wärme in den Zwischenwärmern zwischen den Expansionsstufen gegenüberstehen (im Arbeitsbehälter zwischen Druckminderventil und Zylinder findet natürlich Zwischenwärmung statt), werden geltend gemacht: Durch die Ventilsteuerung ist man in der Lage, den Füllungsgrad des Zylinders beliebig zu verändern, so daß beim Anfahren mit großen Füllungen (0 vH Expansion), bei gleichmäßiger Fahrt aber mit hoher Expansion (bis 50 vH) gearbeitet werden kann. Der Motor ist in jeder Stellung fahrbereit. Eine Füllung des großen Niederdruckzylinders mit Frischluft kommt nicht in Frage. Neben größter Einfachheit der Steuerung und ruhigem Gang ist dadurch gerade beim Anfahren geringer Luftverbrauch erreicht. Die Umlaufzahl derartiger Motoren ist natürlich erheblich höher als die der gewöhnlichen Lokomotivmotoren, so daß eine Kegel- oder Schneckenradübersetzung einzuschalten ist.

Bei Versuchen, die vom Dampfkesselüberwachungsverein Siegen vorgenommen wurden, ergab sich bei Fahrt mit einem 20 t schweren Zuge ein Verbrauch von 0,867 m³ angesogener Luft auf 1 Brutto-tkm. Hier handelt es sich jedoch um besonders günstige Bedingungen, besonders vorzügliche Schienenlage. In Abbaustrecken rechnet die Lieferfirma selbst mit einem Verbrauch von 1,25 m³/tkm, eine Zahl, die von den Lokomotiven mit mehrfacher Dehnung sicherlich nicht übertroffen wird.

Von ähnlichen Gedanken ist die Berliner Maschinenbau-A.-G., vorm. L. Schwartzkopff, bei Konstruktion ihrer Abbaulokomotiven ausgegangen. Sie verwendet einen sternförmigen Fünfzylindermotor, dem die Arbeitsluft von 25 at Spannung aus dem Arbeitsbehälter hinter dem Druckminderventil durch eine Ringleitung zugeführt wird. Der Arbeitsbehälter ist als Zwischenwärmer ausgebildet, so daß die Luft fast mit Grubentemperatur den ebenfalls nach dem Gleichstromverfahren arbeitenden Zylindern zugeführt wird. Durch Verwendung von Leichtmetall für die Kolben wird die Masse der bewegten Teile vermindert. Auf diese Weise ist es gelungen, einen Motor zu bauen, der ruhigen Gang der Lokomotive auch auf schlechtem Gestänge ergibt und wenigstens auf kurzen Förderstrecken den Motoren mit mehrfacher Dehnung hinsichtlich Luftverbrauch überlegen ist. Abb. 8 zeigt eine solche Lokomotive mit abgenommenem Führersitz und gelöstem Motor.

Eine Folge dieser Entwicklung der Abbaulokomotiven ist die jüngste Entwicklung auf dem Gebiete der Hauptstrecken-Lokomotiven: die Firma Schwartzkopff hat einen ähnlich gebauten, sternförmigen Sechszylindermotor herausgebracht, den sie für Druckluftlokomotiven in Hauptstrecken verwenden will, wenn es sich um verhältnismäßig kurze Förderwege handelt. Für lange Förderwege will sie ihre Motoren mit dreifacher Dehnung beibehalten. [B 3169]

[5]) Unfälle im Druckluftlokomotivbetrieb, „Glückauf" Bd. 57 (1921) S. 1284.

COMPRESSED AIR PLANT by Robert Peele
5th Edition 1930

CHAPTER XXIV

COMPRESSED-AIR HAULAGE

For underground transport, compressed-air and electric locomotives divide between them a broad field of operation. Both are applicable to mine service of all kinds, for hauls of a few hundred feet to several miles. For coal mines containing fire-damp, compressed air is perfectly safe, but electric locomotives must be adopted with caution. Although, by the improvements of recent years, much has been done to prevent serious sparking at the motor, some risk still exists; and, furthermore, the possibility of strong sparking, accompanied by the momentary development of intense heat, from short-circuiting or a ruptured conductor, can hardly be averted.

Besides its safety for gassy, or dry, dusty collieries, or in dry and heavily timbered metal mines, compressed-air haulage has the following advantages: (1) Since the power is stored in the locomotive itself, the system has the maximum degree of flexibility; the locomotives can go wherever track is laid, far beyond the end of the supply-pipe line, Electric locomotives, except those having storage batteries, are dependent upon wiring, which must accompany every foot of advance.* For collieries compressed air may be used equally well for main-line haulage, and for gathering and distributing cars among the working places. (2) Compressed air costs little or nothing when not in actual use, and its full power or but a fraction of it is available at all times. In the intervals between hauls, no power is wasted, because, though the compressor may continue running, it is engaged in storing up power in the pipe-line. A minor consideration is that the exhaust of the locomotive discharges fresh air into the workings, improving the ventilation of the mine.

Compressed-air haulage has certain disadvantages, among which are: (1) the danger of high-pressure air, as in case of breakage of pipe couplings at charging stations; (2) occasional difficulty in starting, when the pressure in the auxiliary reservoir has fallen much below normal, and in controlling starting speed when the main tank pressure is momentarily required.

* "Cable-reel" or "gathering" electric locomotives are useful for very short distances only.

At most mines compressed air is employed only for underground transport, from the stopes or breasts to the hoisting shaft. In other cases, where the mine is worked through a tunnel or adit, trains are hauled direct to the breaker, tipple, or ore-bins, on the surface. Occasionally, as at the Homestake Mine, Lead, S. D., compressed-air locomotives are used for surface transport of ore, from the crusher houses at the shaft mouths to the different stamp mills, the object being chiefly to reduce the fire risk for the wooden structures, into and near which the haulage tracks pass. For the same reasons compressed-air haulage may be installed at lumber yards, or factories containing inflammable buildings or materials.

Compressed-air locomotives were probably first used by the Plymouth Cordage Co., Plymouth, Mass., about 1873, and in Great Britain, for mine haulage, in 1878. In the United States perhaps twenty compressed-air locomotives were built previous to 1898.* No material changes in design have been made in recent years.

In general terms, a compressed-air haulage plant comprises a three-stage compressor, receiver, pipe-line, charging stations, and one or more locomotives. The locomotive storage tanks are charged with enough air for a round-trip of the maximum length required, after which the locomotive returns to the nearest charging station for a fresh supply. From the main tank the high-pressure air passes through a reducing valve to an auxiliary reservoir, in which the pressure is about 250 lb., as suitable for the initial pressure in the locomotive cylinders.

The Locomotive has one or two storage tanks, which, with the cylinders and other appurtenances, are mounted on a frame carried by four or six driving wheels. Previous to about 1908, practically all locomotives were single-stage. Due to their greater efficiency and economy in the use of the air, compound (two-stage) locomotives are now the rule. Fig. 1 shows a compact design of a four-wheel, compound locomotive, made in four sizes (Table I).

Small compound locomotives, like that in Fig. 1, have the high-pressure cylinder on one side, the low-pressure on the other. Larger sizes (Figs. 3 and 4) have four cylinders, a high- and a low-pressure, tandem, on each side. For ordinary conditions the cylinder volume ratio is 1 : 4. The initial air pressure is usually 250 lb., which, by expansion in the high-pressure cylinder, is reduced to say 50 lb. As the

* The first compressed-air mine locomotive in the United States was built in 1882 by the Baldwin Locomotive Works, for the Old Eagle colliery, on the Monongahela River, 27 miles above Pittsburgh.

TABLE I.—H. K. PORTER CO.'S TWO-STAGE COMPRESSED-AIR LOCOMOTIVES, CLASS B–P–O

Cylinders — Diameter (in.), high pressure	4½	5½	6	7
Cylinders — Diameter (in.), low pressure	9	11	12	14
Cylinders — Stroke (in.)	10	10	12	14
Diameter of driving wheels (in.)	22	23	24	26
Rigid wheel base (ft. and in.)	2–9	2–9	3–0 or 4–0	4–0
Length over bumpers (ft. and in.)	9 to 12–6	10 to 12–6	12 to 15–6	12 to 18–6
* Extreme width outside gage at cylinders (in.) — H.P.	11	12¾	13	14
* Extreme width outside gage at cylinders (in.) — L.P.	12¼	14¼	15	16½
Height (see note below).				
Main reservoir capacity (cu.ft.) — external volume	20 to 60	30 to 75	60 to 104	60 to 120
Main reservoir length (ft.)	6 to 9	7 to 11	9 to 12–6	9 to 15
Main reservoir diameter (in.)	24 to 36	36 to 40	36 to 40	36 to 40
Main reservoir charging pressure (lb. per sq.in.)	700 to 1,200	700 to 1,200	700 to 1,200	700 to 1,200
Auxiliary reservoir pressure (lb. per sq.in.)	250	250	250	250
Weight in working order (lb.)	7,000 to 10,000	10,000 to 13,000	14,000 to 17,000	18,000 to 22,000
Tractive force (lb.)	1,450	2,200	3,000	4,400
† Hauling capacity—in tons of 2,000 lb. (exclusive of locomotive), 20 lb. per ton rolling friction:				
On absolute level	68	104	142	210
On 1 per cent grade	32	49	67	100
On 2 per cent grade	19	30	42	63
On 3 per cent grade	13	21	29	45
On 5 per cent grade	7	12	17	26
Weight per yard of lightest rail advised (lb.)	16	16	20	30
Radius of sharpest curve advised (ft.)	15	15	20	30
Radius of sharpest curve practicable (ft.)	12	12	15	20

* Width outside of gage line may be reduced by special construction.

† These hauling capacities are maximum for conditions stated. For satisfactory operation train weights should be 50 to 90 per cent of above figures.

NOTE.—Minimum height is dependent upon gage of track; narrow gages require more height than the wider.

expanded air under these conditions leaves the high-pressure cylinder at about 140° F. below atmospheric temperature (say 75°–80° below zero F.), interheating between the cylinders is always necessary.

Fig. 2 shows diagrammatically an efficient "atmospheric" interheater, consisting of a cylindrical shell filled with small brass or aluminum tubes, between which the exhaust air passes (see also Fig. 1, in which the heater is shown in position). The tubes are open at both ends, the heating medium being atmospheric air, drawn through the tubes by the ejector action of the exhaust from the low-pressure cylinder. As the volume of the high-pressure exhaust air is relatively small, its temperature is thus raised almost to that of the atmosphere.

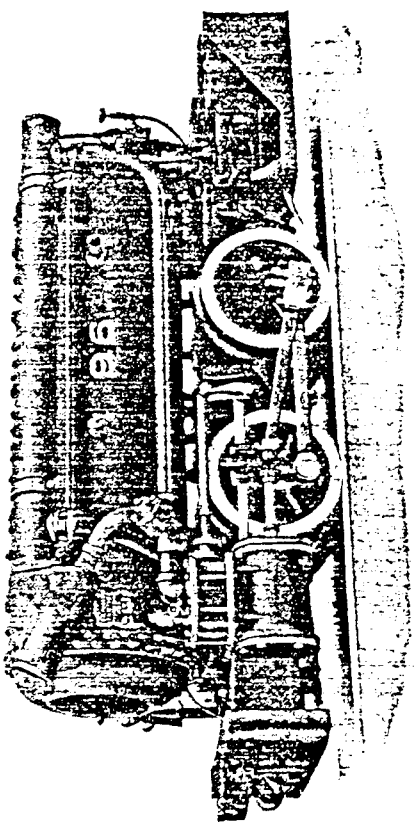


FIG. 1.—H. K. Porter Co.'s Locomotive, Class B–P–O (Table I)

For track with sharp curves, the wheel-base of the locomotive must be short, say 4 ft. 6 in. to 6 ft., for a four-wheel engine. The height of the locomotive over all depends somewhat on the conditions existing in the mine as to thickness of vein, headroom of the haulageways, etc.; it is rarely more than 5 or 6 ft., frequently less. The length varies mainly according to the tank capacity required and the curvature of the gangways. It is usually 10–15 ft. for the smaller sizes, to 20 or 24 ft. for the larger. Widths, 3½–6 ft.

Fig. 3 shows a four-wheel, compound locomotive, made in four sizes (Table II), and Fig. 4 a six-wheel compound (Table III). The hauling capacities given in the tables are maximum for the stated conditions; for satisfactory work, train weights should be 50–90 per cent of those tabulated.

TABLE II.—H. K. PORTER CO.'S TWO-STAGE COMPRESSED-AIR LOCOMOTIVES, CLASS B-PP-O

Cylinders	Diameter (in.), high pressure	7	8½	9½	10
	Diameter (in.), low pressure	14	12 and 12	14 and 14	14 and 14
	Stroke (in.)	14	14	14	14
Diameter of driving wheels (in.)		26	26	26	26
Rigid wheel-base (ft. and in.)		4–0	4–6	4–6	5–0
Length over bumpers (ft.)		14 to 20	16 to 20	18 to 21	20 to 23
* Extreme width outside gage at cylinders (in.)	H.P.	14	15½	16⅛	17¼
	L.P.	16½	16⅝	17⅞	17⅞
Extreme width across main reservoir tanks (ft. and in.)		5–5 to 6–5	5–5 to 6–5	5–10 to 6–10	5–10 to 6–10
* Height above rail (ft. and in.)		5–0 to 5–10	5–0 to 5–10	5–0 to 5–10	5–5 to 5–10
Main reservoir, 2 tanks, capacity (cu.ft.)		97 to 160	114 to 210	160 to 275	160 to 290
Main reservoir lengths (ft.)		10 to 18	12 to 18	14 to 20	16 to 21
Main reservoir diameters (in.)		30 to 36	30 to 36	32½ to 38½	32½ to 38½
Main reservoir charging pressure (lb. per sq.in.)		700 to 1,200	700 to 1,200	700 to 1,200	700 to 1,200
Auxiliary reservoir pressure (lb. per sq.in.)		250	250	250	250
Weight in working order (lb.)		20,000 to 27,000	28,000 to 36,000	32,000 to 42,000	43,000 to 46,000
Tractive force (lb.)		4,400	6,400	8,000	9,000
Hauling capacity—in tons of 2,000 lb. (exclusive of locomotive), 20 lb. per ton rolling friction:					
On absolute level		206	305	380	437
On 1 per cent grade		96	145	180	207
On 2 per cent grade		59	92	113	130
On 3 per cent grade		31	65	80	92
On 5 per cent grade		22	38	46	53
Weight per yard of lightest rail advised (lb.)		30	40	45	50
Radius of sharpest curve advised (ft.)		30	35	40	50
Radius of sharpest curve practicable (ft.)		16	18	20	25

* This may be decreased in special cases.

TABLE III.—H. K. PORTER CO.'S TWO-STAGE COMPRESSED-AIR LOCOMOTIVES, CLASS C-PP

Cylinders	Diameter (in.) H.P.	7	8½	9½	10
	Diameter (in.), L.P.	14	12 and 12	14 and 14	14 and 14
	Stroke (in.)	14	14	14	14
Diameter of driving wheels (in.)		26	26	26	26
Rigid wheel-base (ft. and in.)		5–6	5–6	5–6	6–6
Length over bumpers (ft.)		14 to 20	16 to 20	18 to 21	20 to 23
* Extreme width outside gage at cylinders (in.)	H.P.	14	15½	16⅛	17¼
	L.P.	16½	16⅝	17⅞	17⅞
Extreme width across main reservoir tanks (ft. and in.)		5–5 to 6–5	5–5 to 6–5	5–10 to 6–10	5–10 to 6–10
Height above rail (ft. and in.)		5–0 to 5–10	5–0 to 5–10	5–0 to 5–10	5–0 to 5–10
Main reservoir (2 tanks) capacity (cu.ft.)		97 to 160	114 to 210	160 to 275	160 to 290
Main reservoir lengths (ft.)		10 to 18	12 to 18	14 to 20	16 to 21
Main reservoir diameters (in.)		30 to 36	30 to 36	32½ to 38½	32½ to 38½
Main reservoir charging pressure (lb. per sq.in.)		700 to 1,200	700 to 1,200	700 to 1,200	700 to 1,200
Auxiliary reservoir pressure (lb. per sq.in.)		250	250	250	250
Weight in working order (lb.)		20,000 to 27,000	28,000 to 36,000	32,000 to 42,000	43,000 to 46,000
Tractive force (lb.)		4,400	6,400	8,000	9,200
Hauling capacity		The figures in Table II apply here also.			
Weight per yard of lightest rail advised (lb.)		25	30	35	40
Radius of sharpest curve advised (ft.)		50	50	50	70
Radius of sharpest curve practicable (ft.)		30	30	30	50

* This may be decreased in special cases.

Fig. 5 shows a small locomotive with 4 by 7-in. cylinders. The operator's seat is detachable, so that the locomotive can be transferred from one level of a mine to another, on a cage with a 5-ft. platform. This design is suitable for small metal mines, or for gathering cars from working places in collieries, to make up trains on main haulageways. For mines having very steep local grades, the H. K. Porter Co. has

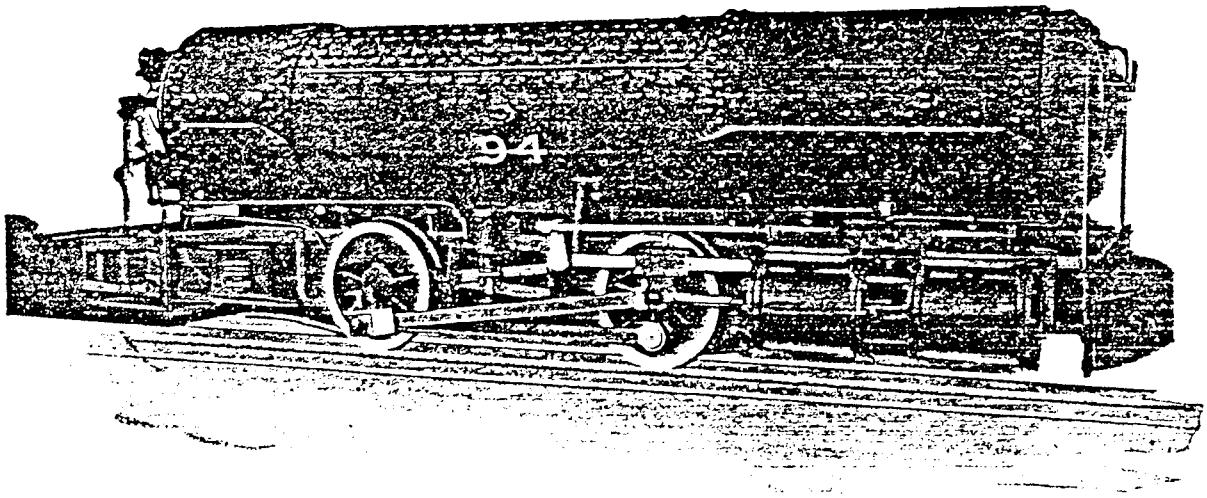


FIG. 3.—H. K. Porter Co.'s Two-stage Locomotive, Class B-PP-O.

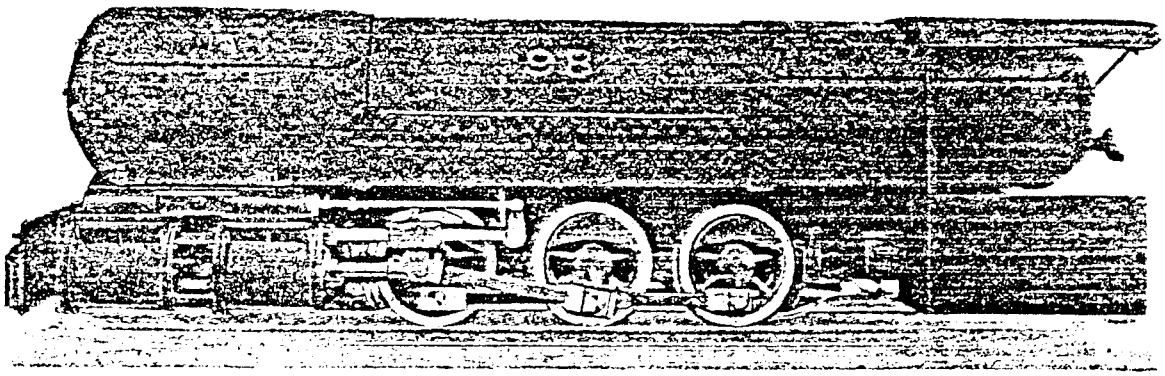


FIG. 4.—H. K. Porter Co.'s Two-stage Locomotive, Class C-PP.

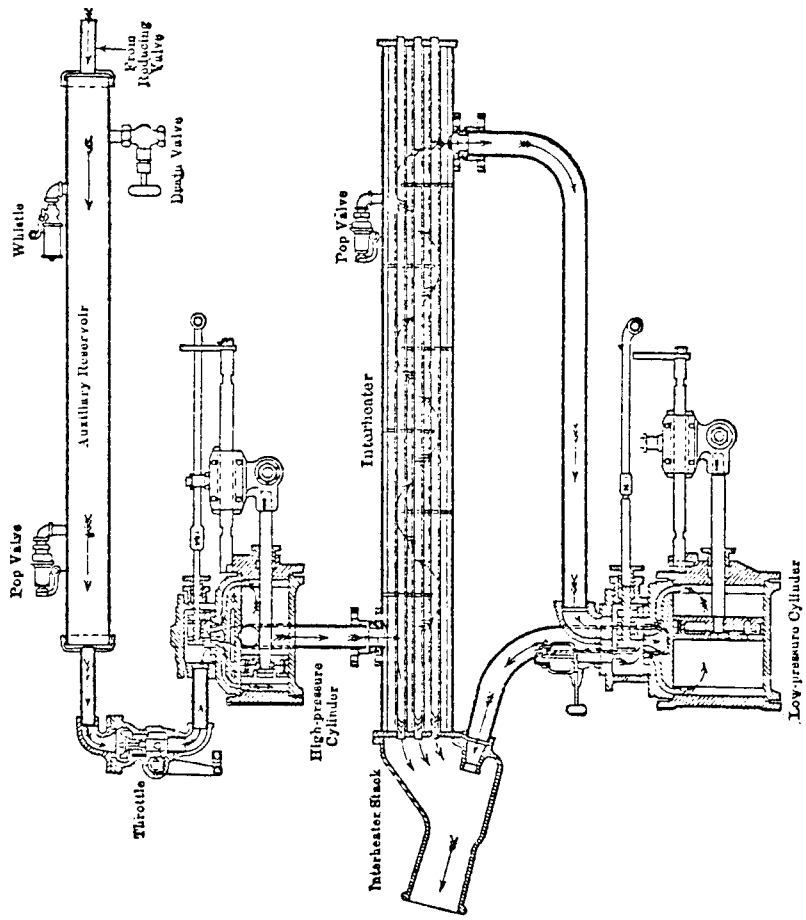


FIG. 2.—Diagram of Interheater and Cylinders for H. K. Porter Co.'s Two-stage Locomotives

built locomotives like that in Fig. 1, but with a cable-reel on the rear. This operates like an ordinary locomotive on easy grades, and serves also as a hoisting engine to gather cars from steep cross entries or breasts. The reel, holding 300–1,000 ft. of wire rope, is driven by a pair of small auxiliary cylinders. Fig. 6 is a diagram of the rear end of a locomotive like that in Fig. 1. It shows the course of the air from the main tank

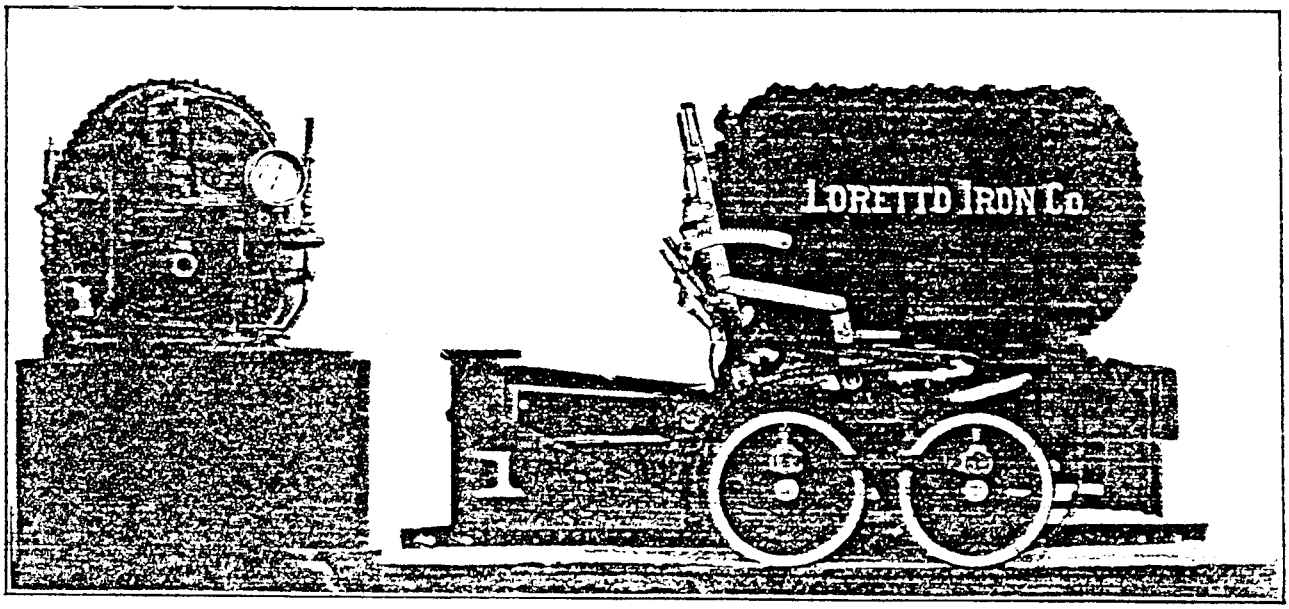


FIG. 5.—H. K. Porter Co.'s Locomotive for Small-scale Work.

FIG. 6.—Diagram of Air Piping, Interheater, Valves, etc., on Rear End of Two-stage Locomotive (H. K. Porter Co.)

to the auxiliary reservoir, thence through a by-pass valve to the reheater, and finally to the cylinders.

Locomotive Details.—The tanks have dished or approximately hemispherical ends, and are built of heavy boiler plate, with a tensile strength of 60,000–68,000 lb. per sq. in.; the shells are ⅜ to ½ in. thick,

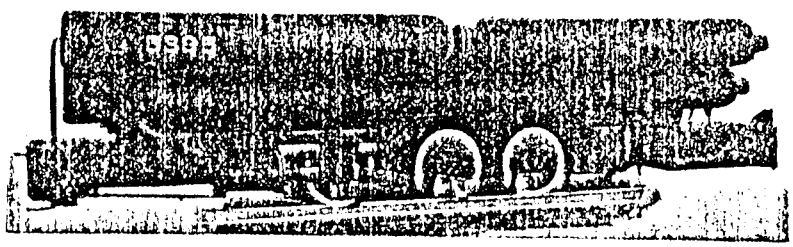


FIG. 7.—H. K. Porter Co.'s Locomotive, Class C–5Ps–O.

with 1 to 1¼-in. heads. Ring seams are double riveted with lap joints; longitudinal seams have butt joints, with inside and outside welt strips. As the tanks are generally designed for working pressures of 700–900 lb., the longitudinal seams have 6–8 rows of rivets, to make a joint of not less than 75 per cent of the strength of the plate. Tanks are tested with a pressure about 30 per cent greater than the working pressure, the factor of safety with plate of the usual quality being about 3½; this is sufficient, as there are no expansion and contraction strains as in a boiler. For very high pressures, tanks of large diameter are unsafe, and are replaced by several smaller tanks (Fig. 7), or by a set of heavy seamless steel tubes, 8 to 9 in. in diameter. Tubes 9 in. in diameter by ½½ in. thick will carry pressures of 2,000–2,200 lb. per sq. in. These high pressures are unnecessary for ordinary haulage service.

From the main tank the air passes into a small auxiliary reservoir and thence to the cylinders. This reservoir is usually a section of wrought-iron pipe, 4 to 9 in. in diameter and 6 to 15 ft. long, laid alongside the main tank. The pressure in it is adjusted by an automatic reducing valve to the requirements of the engine—usually 140 to 150 lb. for single-stage, and 250 to 300 lb. for two-stage locomotives, depending on the size of cylinders and the power required. On the locomotives of the H. K. Porter Co., the reducing valve is a double-seated balanced valve, operated by a small piston. The air pressure in the reservoir acts on one side of the piston, tending to close the valve. This action is opposed by an external spring, adjusted to keep the valve open until normal working pressure is reached in the reservoir. Then the valve is closed by the air pressure, against the spring resistance. To provide for the case when the locomotive is using no air (as on a down grade or when at rest), a single-seated supplementary valve is placed in the pipe between the reducing valve and the main tank. This valve is controlled by the throttle lever; being open when the throttle is open, otherwise closed by the air pressure. Having the two valves, leakage from main tanks to auxiliary reservoir is avoided and a close regulation secured.

From the auxiliary reservoir the air passes to the cylinders through a balanced throttle valve. This maintains a constant working pressure, suited to the needs of the locomotive, prevents waste of air likely to ensue if air at full tank pressure were admitted to the cylinders, and makes the locomotive more manageable. In starting a heavy load excessive slipping of the drivers is avoided, and with light loads the reducing valve may be regulated for any desired pressure. Toward the end of the trip, when the pressure in the main tanks falls to that in the auxiliary, the cylinders take air directly from the former, and the locomotive will continue to run as long as the pressure remains sufficient. For long hauls, or when the cross-sectional dimensions or sharp curves, or both, of the haulage-ways do not permit the use of tanks of great length or large diameter, a tender carrying a supplementary tank may be employed (Fig. 8).

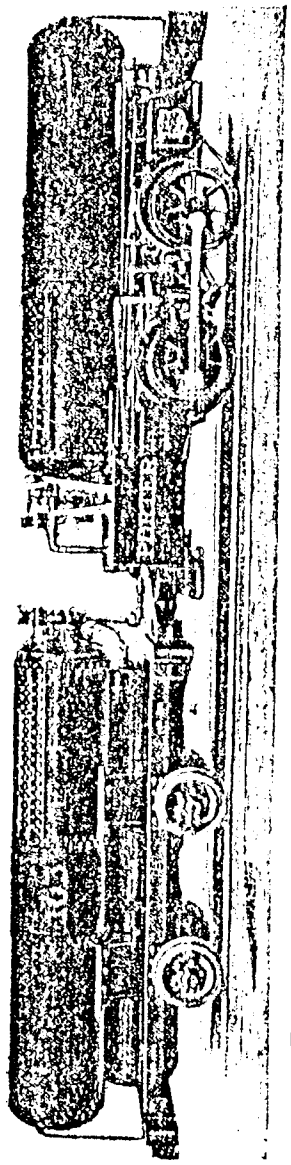


Fig. 8.—H. K. Porter Co.'s Locomotive, Class B-PP-T (Cylinders are inside of the frame).

For small, single-stage locomotives, the air is sometimes admitted to the cylinders throughout nearly full stroke, and consequently, as the exhaust is at high pressure, the efficiency is low. This practice is due to the tendency to use as small a locomotive as possible, on account of the limited headroom and narrow, crooked gangways so common in mines. Better results are obtained by working with a cutoff, and increasing the size of the cylinders and the weight on the drivers. In using air expansively, as can be done with properly proportioned cylinders, there should be no trouble from freezing of moisture. Although expansion produces a low cylinder temperature, yet, as the initial pressure is so much higher than is employed for other compressed-air

machinery, the expanded air is relatively dry, and the force of the exhaust is sufficient to keep the ports clear of ice. To this end the ports should be large, straight, and short. The cylinders are not lagged with non-conducting covering, as is so necessary for steam cylinders, to minimize condensation. By exposing their surface to the warm air of the mine, some heat is absorbed. Occasionally the exterior surface of the cylinders is cast with deep corrugations, to present a large area to the warm surrounding air. The cylinders are provided with slide valves; piston valves, like those used in steam locomotives, would leak more because of the dryness of the air.

On account of the cold produced by reducing the pressure between the main tank and auxiliary reservoir, and to increase efficiency of operation, reheating is advantageous (though not essential) for single-stage locomotives. It is best done by heating the auxiliary reservoir. If steam is available in the mine, a little steam and hot water may be injected into the reservoir each time the locomotive is charged. Or, in mines free from fire-damp, a small reheater, burning oil or coke, may be carried on the locomotive. When the air is reheated water should always be kept in the small tank; the moisture from it, passing with the air into the cylinders, assists in lubricating the valves and pistons. For compound locomotives interheating only is necessary, applied between the cylinders (see Fig. 2 and accompanying description).

Pipe-line and Charging Stations.—The required capacity of the plant depends on the length of haul and size of locomotives, as influenced by the daily output, weight of trains, and track gradients. For short hauls, the pipe-line is sometimes omitted, the locomotive returning to the compressor receiver to be recharged. Usually a pipe-line is carried underground, with charging stations at one or more points, located according to the haulage distances and the capacity of the locomotive tanks. The innermost station, farthest from the compressor, must be at a point from which the locomotive can reach the end of its trip and return for recharging. For long hauls, heavy traffic, or adverse gradients, several charging stations may be required. Inside receivers are unnecessary, unless the diameter of the pipe-line is too small. The pipe-line itself acts as a storage reservoir, and should be of a diameter which, in proportion to its length, will furnish a cubic capacity sufficient to charge the locomotive tank quickly and without excessive drop in pressure. That is, the pressure in the tank and pipe-line on equalizing should not fall much below the pressure which the locomotive is designed to carry. To this end, the volume of pipe-line storage should be at least three times the tank capacity of the locomotive. To determine the necessary pipe-line capacity, several variables must be harmonized, as follows: *

V = storage volume required, cubic feet;
v = volume of locomotive tank, cubic feet;
P = pipe-line pressure, pounds per square inch (usually 900–1,200 lb.);
p = desired pressure in locomotive tank, pounds per square inch (700–900 lb.);
p' = residual pressure in locomotive tank, just before recharging, pounds per square inch.

Then: $V(P - p) = v\,(p - p')$, or $V = \dfrac{v(p - p')}{P - p}$.

For example, let P = 900 lb., p = 750 lb., p' = 125 lb., and v = 100 cu.ft., from which:

$$V = \frac{100(750 - 125)}{900 - 750} = 416.6 \text{ cu.ft.}$$

By transposition, the same formula serves for finding the pipe-line pressure required for a given tank pressure. When there are several locomotives, it is rarely necessary to design the pipe-line for charging more than one at a time. If the volumetric capacity of the pipe-line is ample, the drop in gage pressure on charging is soon recovered by the compressor, which, except in plants operating a single locomotive, is kept in nearly constant operation. If more locomotives are added after the original installation of the system, the same pipe-line may still serve, provided the compressor is able to charge it to full pressure at shorter intervals

The piping, which is generally from 3 to 5 in., should be of the best material, lap-welded, and should have sleeve joints made with the utmost care to prevent leakage. To stop leaks, the sleeves should have annular grooves (counter-bores) at each end, into which lead calking is driven if required. About every 300 ft. a pair of flanges should be placed in the line, and valves at suitable places, for convenience in making repairs or extensions. There should also be a valve between the compressor and pipe-line, so that the compressor can be inspected or repaired without wasting the air in the pipe. The pipe should not be buried, but carried along one side of the haulageway, either on the floor or on brackets, so that leaks will at once attract attention. An occasional bend in the pipe-line is advantageous in permitting free expansion and contraction, but bends should not be too numerous, as they involve

* H. K. Porter Co., "Modern Compressed-Air Locomotives."

more joints and greater possibility of leakage. Pipe-lines should be painted with some non-corrosive coating.

Charging Stations.—Fig. 9 shows one design, consisting of a heavy tee inserted in the air main, with a flexible connection for coupling to the locomotive. The connecting pipe comprises a vertical, rigid branch, with a $1\frac{1}{2}$-in. gate-valve, and a short horizontal pipe, with a union and a ball-and-socket joint. A further flexible connection, with two ball joints, serves for coupling to the locomotive tank. Thus, for charging, the locomotive need not be spotted accurately on its track, but has a

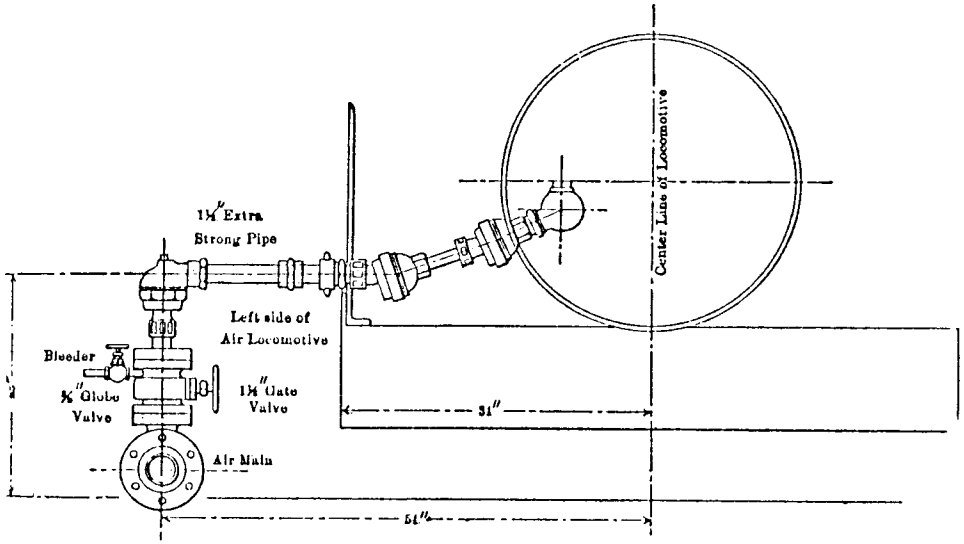


Fig. 9.—Compressed-air Locomotive Charging Station.

foot or two leeway. When not in use, the flexible connection is swung aside.

After coupling to the locomotive, the gate-valve is opened, whereupon the air pressure immediately forces together the parts of the ball-and-socket joints and makes a tight connection. When equilibrium is established between the pressures in the pipe-line and tank, the gate-valve is closed. To break the coupling, the compressed air remaining in the connecting pipe, between the gate-valve and the locomotive check-valve, must first be released. This is done by opening a small "bleeder valve," placed just above the gate-valve. The joints then loosen and are readily manipulated. The actual time occupied in charging is usually about three-quarters of a minute, but, including stopping the locomotive and making the connection, $1\frac{1}{2}$–2 minutes may be allowed. Charging may often be done while shifting cars and making up trains. Fig. 10 shows another form of charging station.

Calculation of Motive Power.—Several factors must be known: the tractive resistance per ton of the loaded cars on a level, resistances due

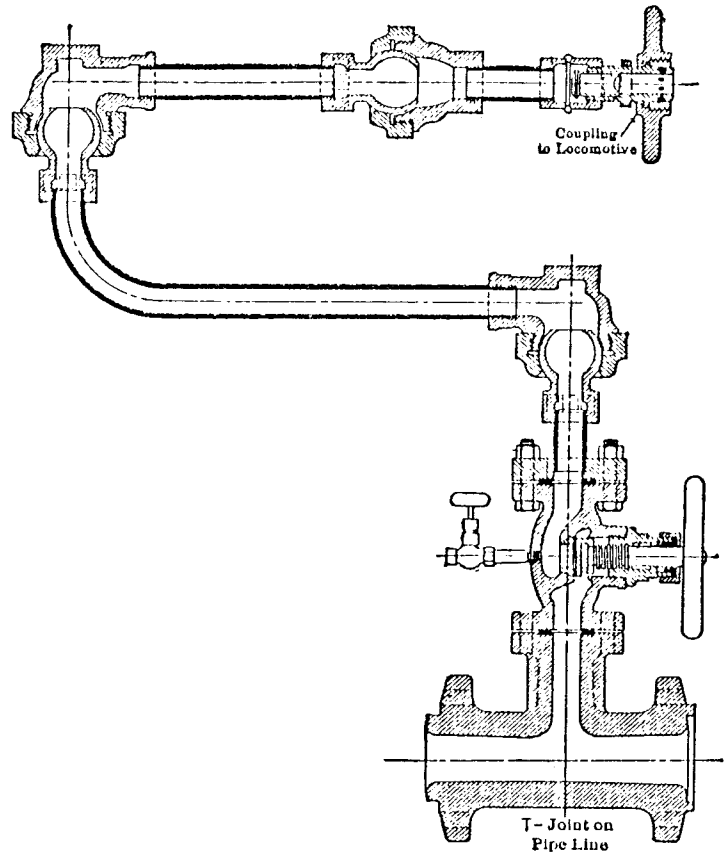


Fig. 10.—Charging Station (H. K. Porter Co.)

to gradients and curves, weight of empty and of loaded cars, and number of cars to be hauled per train. The values of these factors are readily ascertained, with exception of the resistances due to curvature of track and character of roadbed. The former has been determined experimentally for ordinary surface railways, but mine track is apt to be roughly laid, with curves of varying and irregular radius, and the elevation of the outer rail improperly adjusted.

The average tractive force required per ton depends on the condition of the track and roadbed, and the character and state of repair of the running gear of the cars. On level mine track the coefficient of rolling friction is usually from 30 to 40 lb. per ton, though it may be considerably higher on poorly laid or light track. With mine track in exceptionally good condition, this coefficient may be as low as 20 lb. The grade resistance is 20 lb. per short ton, for each 1 per cent of grade. The distribution of grades is often such that the maximum load is not the resistance of the loaded trains, which are usually hauled on slight down grades, but that of the return trains of empty cars on adverse gradients. For the most economical work, gradients should not exceed $\frac{1}{2}$ to $\frac{3}{4}$ per cent in favor of the loaded trains. With ordinary track and rolling stock, and a grade of 5 or 6 in. per 100 ft., the coefficient of rolling friction is nearly the same for a loaded train hauled down as for an empty train of the same number of cars hauled up the grade. Heavier adverse grades are often necessary ($2\frac{1}{2}$ or 3 per cent or more), but they should be avoided, because the maximum tractive force of a locomotive falls off rapidly. On a $2\frac{1}{2}$ per cent adverse grade the locomotive can haul only about four times its own weight, even if the track is not slippery. Grades should be reduced on curves. Colliery cars carrying $2\frac{1}{2}$ to $3\frac{1}{2}$ tons weigh 1,800 to 2,300 lb., whereas those used in metalliferous mines, for mechanical haulage, weigh 1,000 and 2,000 lb. Having ascertained the values of the different factors, the proper allowance of reserve power, in terms of volume and pressure of air, to cover indeterminate resistances due to local imperfections of track and rolling stock, is a matter of judgment and experience.

With a given air pressure, the capacity of the locomotive tanks depends primarily on the length of round trip to be made with a single charge of air. When this distance is 1 or $1\frac{1}{2}$ miles, the tank capacity is generally from 50 to 150 cu.ft., according to the load; which, in turn, together with the track and grade resistances, governs the cylinder dimensions. Cylinders of 5 by 10 in. up to 9 by 14 in. are common, the larger sizes being for heavy work in collieries or on surface. For runs exceeding $1\frac{1}{2}$ miles, it is often desirable to increase the air pressure, rather than the tank capacity. Another plan is to provide a tender, carrying an auxiliary tank (Fig. 8).

Having determined the total foot-pounds of work to be done with a single charge of air, on a run of the maximum length, specifications may be obtained from the builders for a locomotive of suitable weight, gage, wheel-base, tank capacity, and cylinder dimensions.

Compressors for Charging Locomotives are usually three-stage, occasionally four-stage. The air cylinders of the higher stages are single-acting. Examples are shown by Figs. 30 and 31, Chapter III, with their accompanying specifications.

When the mine is already provided with a low-pressure air plant, for machine drills, etc., and if it has some surplus capacity, a two-stage charging compressor may be installed, to take air from the low-pressure system and bring it up to the tension required for the locomotives. Care must be exercised in making such a combination, and it is not advisable. If the quantity of air from the low-pressure compressor should at times be insufficient to furnish the necessary excess for the locomotive charger, the latter might have to compress from too low an initial pressure. There would then be excessive development of heat which might raise the cylinder temperature to the flashing-point of the oil, thus causing an explosion (Chapter XIII).

The capacity of the charging compressor depends on the pipe-line pressure, number of locomotives to be operated, cubic contents of the locomotive tanks, pressure carried by the system, and the relation between charging periods.

Let C = compressor capacity required, cubic feet free air per minute;
L = locomotive-tank capacity, cubic feet free air per minute;
N = number of charges required in any given time, T.

Hence the equation: $C = \frac{NL}{T}$.

For example, if $N = 3$, $L = 5{,}200$ (corresponding to 100 cu.ft. of air at 750 lb. gage pressure), and $T = 60$ minutes:

$$C = \frac{3 \times 5{,}200}{60} = 260 \text{ cu.ft. free air per minute.}$$

When the locomotives are charged at approximately equal intervals of time, a single application of the above formula will be sufficient. Otherwise, calculations are required to determine the maximum and minimum rates of consumption of air. For plants installed at an altitude above sea-level, allowance must be made for decreased compressor output (Chapter XII).

Examples of Compressed-air Haulage Plants are given in Table IV.

The following data are on a plant of the Philadelphia & Reading Coal & Iron Co.:

(*a*) Shaft level—1 locomotive.

Round trip 5,200 ft.; grades $\frac{4}{10}$ to $\frac{8}{10}$ per cent, all in favor of load; charging station at each end of run; gage of track, 44 in.; weight of cars, empty, 3,300 lb.,

TABLE IV.—DATA ON COMPRESSED-AIR HAULAGE PLANTS (Dec., 1929)

	U. S. S. R. & Mining Co., Bingham Canyon, Utah		Ray Mine, Arizona	Inspiration Mine, Arizona	Philadelphia & Reading Coal & Iron Co.	Homestake Mine, South Dakota			
	Main	Intermediate							
Number of locomotives in use	3*	3†	23§	18	42	2	2	20	10
Weight of locomotive, pounds	16,000	8,000	16,500	20,000	14,000–25,700	28,000¶ / 26,000	17,000	10,000	7,000
Dimensions, inches:									
Width	48	45	58	64	79	63	52	40	36
Height	65	58	61	69	64	82	76	61	57
Length	164	127	208	192	192	276 and 256	178	106–135	106
Track gage, inches	18	18 and 24	30	30	44 and 48	22	22	18	18
Draw-bar pull, pounds	3,000	1,450	3,000	5,000	3,500–4,500	6,400	3,000	2,200	1,450
Capacity, main tank, cubic feet	90	40	82	105	78–110	165 and 137	70	28.5–40	20.5
Capacity auxiliary tank, cubic inches	.....	.....	2,488	.....	5,040	4,368 / 3,456	2,550	990–1,340	640
Tank pressure, pounds	900	900	850	800	900	900	900	900	900
Initial cylinder pressure, pounds	250	250	200	250	150–300	250 and 170	170	145	145
Cars per train	7	8	20–30	25 (max.)	8–18	31	11	25	12
Weight of car, pounds	8,300	1,900	3,600	3,900–5,475	5,000	5,100	5,100	1,200–1,600	
Weight of car contents, pounds	16,000	4,000	10,000	9,000–10,000	8,550	9,400	9,400	2,000	2,000
Cost of haulage per ton-mile, cents	10.56‡	13.05‡	.....	13.0	4.0	.....	.....	.....	.....

NOTES.—All locomotives listed above were built by the H. K. Porter Co., except 10 of those in the Philadelphia & Reading Coal & Iron Co.'s mines, which are by the Baldwin Locomotive Works. Locomotives working with initial cylinder pressures of 250 lb. and over have compound cylinders; the others have simple cylinders.

* Cylinders, 6 by 12 by 12 in. † Cylinders, 4½ by 9 by 10 in. ‡ Total cost except depreciation.
§ Average haul, 0.83 mile (in this mine air haulage is being gradually superseded by electric haulage). ¶ For surface haulage, shafts to ore bins.

loaded, 8,800 lb.; 15–38 cars per trip; total output, 600 cars per 10 hours. Round-trip time, 12 min.; charging time, 1 min. A round trip and a half can be made with one charging.

(5) Slope level—1 locomotive.

Length of haul, 3,200 ft., of which 700 ft. is on an adverse grade of $4\frac{1}{10}$ to 5½ per cent. Grade of main gangway, $\frac{4}{10}$ to $\frac{8}{10}$ of 1 per cent, in favor of load. Trains of 10 cars are hauled on main gangway, and 4 cars on the slope; weights of cars same as above.

Locomotive-tank pressure at start, 600 lb.; at end of trip, 200 lb. Average working pressure, 180 lb.

The cost of the plant and its operation was as follows (pre-war prices):

One Norwalk 3-stage compressor, erected	$5,180.74
Pipe-line, 4,200 ft., 5 in., including three charging stations	2,951.06
Two Baldwin compressed-air locomotives and fittings	4,901.33
Alterations in gangways to adapt them to locomotive haulage	665.17
Total cost	$13,701.30
Daily operating cost, for 180 days in the year	$14.69
Fixed charges, depreciation, repairs, etc., figured at 10 per cent, together with cost of steam power	9.00
Total running expenses per day	$23.69
Haulage cost per car, at 660 cars per day	3.6 cents
Previous cost of mule haulage per car	5.1 cents
Saving per year, about	$1,800.00

For full operating details and costs of an old compressed-air haulage plant at a Pennsylvania anthracite mine, see *Trans.* Amer. Inst. Min. Engs., Vol. XXX, p. 566.

March 22, 1930
v. 74, p. 366-368

Diesellokomotive mit Druckluftübertragung[1)]

Von Dr.-Ing. J. GEIGER, Augsburg

Die Erwägungen thermischen und konstruktiven Charakters bei der Ausarbeitung der Druckluft-Übertragung werden besprochen. Die erste behelfsmäßige Versuchsanlage gab Aufschluß über den Wirkungsgrad der Übertragung und die Betriebssicherheit bei Ausnutzung der Abgaswärme. Die endgültige Ausführung zeigt die Maßnahmen zur Erzielung eines möglichst hohen Liefergrades.

Als im Jahre 1925 anläßlich der 64. Hauptversammlung des Vereines deutscher Ingenieure zu Augsburg durch den Vortrag „Dieselmotor und Kraftübertragung bei Großöllokomotiven“[2)] bekannt wurde, daß die MAN zusammen mit der Maschinenfabrik Eßlingen für die Deutsche Reichsbahn eine Diesellokomotive mit Druckluftübertragung bauen wolle, wurde diese Mitteilung von vielen Seiten mit Kopfschütteln aufgenommen. Man bezweifelte nicht nur den errechneten Wirkungsgrad von fast 26 vH, sondern auch ernsthafte Fachleute sprachen von „Eisfabrik auf Rädern“, schlechtem Wirkungsgrad, verwickeltem Zusammenbau von drei Maschinen (Dieselmotor, Kompressor und Luftmaschine), Ölexplosionen und Lebensgefahr für die Besatzung. Diese Bedenken kennzeichneten den Ernst der Sachlage und die zu überwindenden Schwierigkeiten.

Worauf man sich damals stützen konnte, das waren theoretische Untersuchungen, die bereits Ende 1918 und Anfang 1919 durchgeführt worden waren. Sie hatten die Möglichkeit gezeigt, insbesondre durch Ausnutzen der Abwärme der Auspuffgase den Wirkungsgrad der Übertragung erheblich zu verbessern. Es schien daher wichtig, das Verfahren an einer Versuchsanlage zu erproben.

Diese Anlage, Abb. 1 und 2, die behelfsmäßig aus vorhandenen Maschinen und Teilen zusammengestellt wurde, bestand aus einem elektrisch angetriebenen Kompressor *a*, einem Druckluftkessel *b*, einer Meßdüse *c*, einem Wasserabscheider *d*, einem Lufterhitzer *e* und endlich einer liegenden Luftexpansionsmaschine *f*. Der Kompressor war der Teil eines 1200 PS-U-Boot-Motors, von dem man das Triebwerk der Dieselzylinder und die Hochdruckseite des Einblasekompressors entfernt hatte. Der Erhitzer wurde mit Auspuffgasen einer in der Nähe stehenden Dieselmaschine beheizt. Die Druckluftmaschine war eine alte Dampfmaschine mit Riderschieber. Die Versuche bezweckten, nicht nur den Wirkungsgrad der Übertragung für gegebene Verhältnisse festzustellen, sondern insbesondre auch den Druck zu ermitteln, bei welchem der Wirkungsgrad den Größtwert erreichte. Außerdem sollte die Betriebsicherheit, z. B. die Möglichkeit von Ölexplosionen oder Eisbildung, geprüft werden. Aus den damaligen Versuchsergebnissen sei folgendes hervorgehoben:

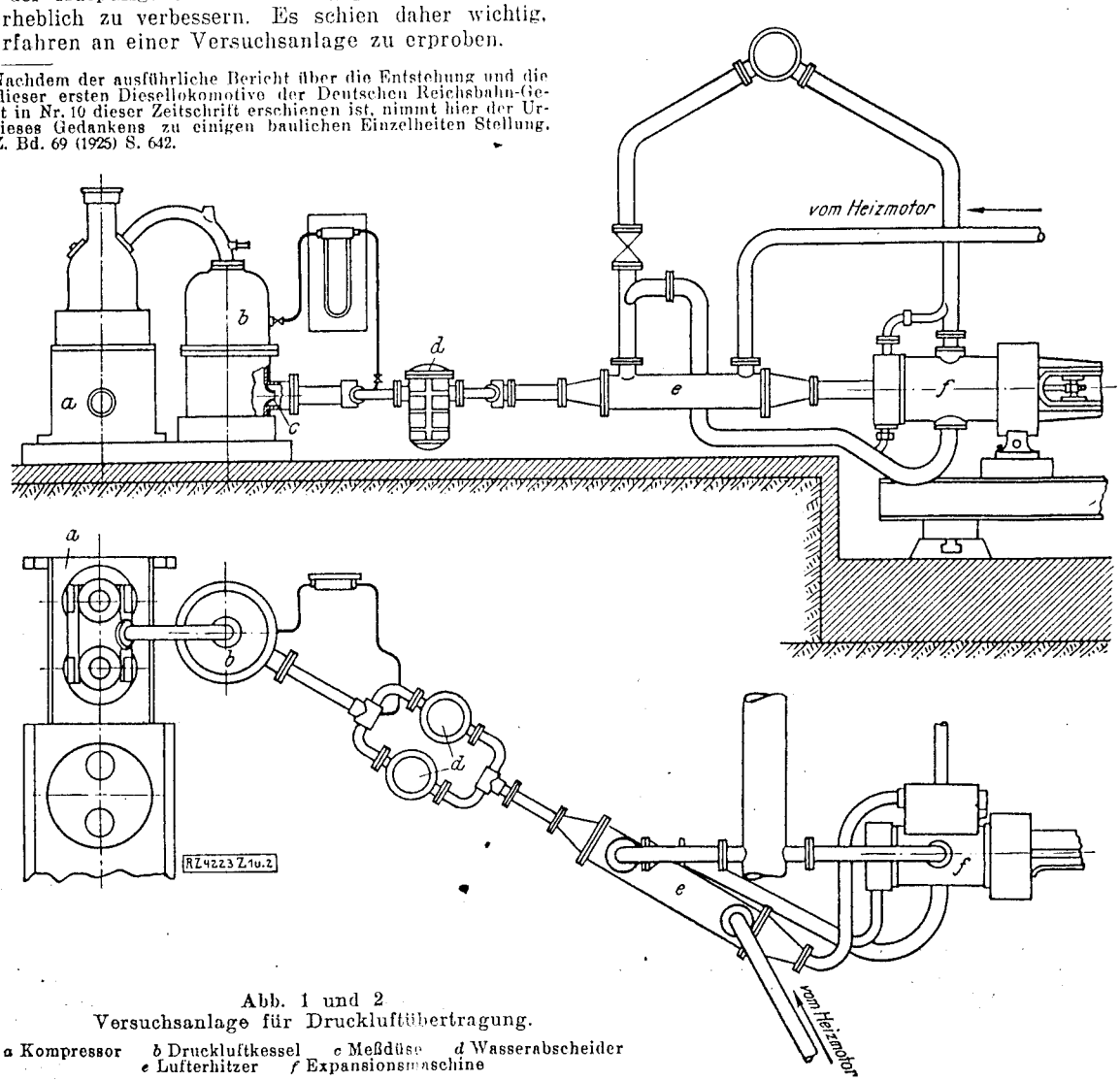


Abb. 1 und 2
Versuchsanlage für Druckluftübertragung.
a Kompressor *b* Druckluftkessel *c* Meßdüse *d* Wasserabscheider
e Lufterhitzer *f* Expansionsmaschine

[1)] Nachdem der ausführliche Bericht über die Entstehung und die Bauart dieser ersten Diesellokomotive der Deutschen Reichsbahn-Gesellschaft in Nr. 10 dieser Zeitschrift erschienen ist, nimmt hier der Urheber dieses Gedankens zu einigen baulichen Einzelheiten Stellung.

[2)] Z. Bd. 69 (1925) S. 642.

1. Den höchsten Wirkungsgrad ergab die Übertragung mit Druckluft von 3 at Überdruck.
2. Der indizierte Wirkungsgrad (indizierte Leistung der Druckluftmaschine zu indizierter Leistung des Kompressors) stieg bei Druckluft von 3 at und 250 ° bis auf 94 vH; der nutzbare Wirkungsgrad erreichte fast 70 vH.
3. Eisbildung, auch bei kalter Anlage, Ölbrände oder Explosionen sind nicht aufgetreten.

Die Versuche hatten also bewiesen, daß man durch Ausnutzen der Abgaswärme den Wirkungsgrad erheblich über den bisher bei Druckluftübertragungen erzielten steigern kann, ohne daß die Betriebsicherheit abnimmt.

Bei Anwendung dieser Ergebnisse auf eine Lokomotive waren aber noch manche Schwierigkeiten zu überwinden. Unter anderem war es ausgeschlossen, mit Druckluft von 3 at Lokomotivzylinder zu betreiben; sie hätten unausführbar große Abmessungen erhalten. Weiter mußte man auf der Lokomotive mit viel kleinerem Raum und Gewicht auskommen.

Dieses Ziel wurde erreicht durch sorgfältige Untersuchung aller Verlustquellen; hierdurch wurde die Bauart aller Teile der Druckluftübertragung mit Ausnahme der Lokomotivzylinder und ihres Triebwerkes beeinflußt. Außerdem kam ein neues Mittel, die Wassereinspritzung zum Kühlen des Kompressors zur Verwendung.

Steuerung des Kompressors

Um einen möglichst hohen Liefergrad und damit auch einen guten thermischen Wirkungsgrad des Kompressors zu erreichen, wurde der schädliche Raum des Kompressors so klein wie möglich bemessen. Da mit Rücksicht auf Wärmedehnungen und Zapfenspiel ein gewisser Abstand zwischen Zylinderdeckel und Kolben beibehalten werden muß, trachtete man, Tatsachen für Ventile oder sonstige Teile der Steuerung zu vermeiden. Daher wurden Ventile für die Steuerung gewählt und diese vollständig im Zylinderdeckel untergebracht.

Selbsttätige Saugventile der üblichen Ausführung haben, wie Versuche zeigten, einen ziemlich großen Widerstand, der schon bei Drehzahlen von 90 bis 100 U/min den Liefergrad vermindert. Das konnte sich hier um so schlimmer auswirken, als mit Rücksicht auf Raum und Gewicht für den 1200 PS-Dieselkompressor die Drehzahl von 450 U/min gewählt werden mußte. Für jede Kolbenseite wurden daher zwei von einem gemeinsamen Nocken gesteuerte Saugventile verwendet.

Die Auslaßsteuerung wurde besonders gründlichen Versuchen unterworfen. Die jetzt eingebauten selbsttätigen Druckventile, Abb. 3 und 4, bestehen aus je fünf konzentrischen Ringplatten, die durch schwache zylindrische Schraubenfedern niedergedrückt werden.

Der Kompressor ist mit dem Dieselmotor ohne Kupplung zu einem steifen Ganzen vereinigt. Seine Grundplatte ist eine Fortsetzung der Grundplatte des Dieselmotors und hat die gleichen Abmessungen wie diese. Das letzte Lager des Dieselmotors ist zugleich das erste Lager des Kompressors. Durch diesen festen Zusammenbau wurde an Raum und Gewicht gespart und eine Versteifung des Lokomotivrahmens erreicht.

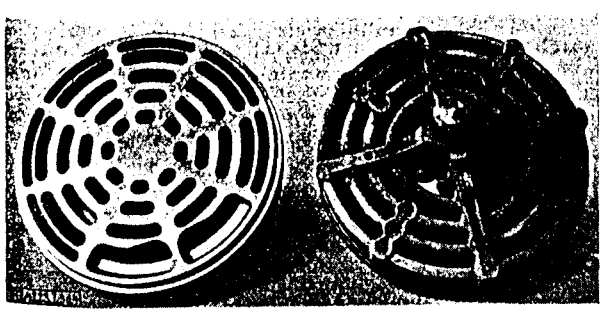


Abb. 3 und 4
Druckventil, aufgenommen unmittelbar nach Erledigung sämtlicher Probefahrten, in ungereinigtem Zustande.

Abb. 3. Blick auf den Ventilsitz.

Abb. 4. Blick auf den Ventilfänger.

Für den Wirkungsgrad der Übertragung wichtig ist die erhebliche Verbesserung des mechanischen Wirkungsgrades des Kompressors. Sie zeigte sich darin, daß der mechanische Wirkungsgrad der gesamten Gruppe auffallend hoch war. Etwas beigetragen hat hierzu auch das Fehlen des Schwungrades; zum Schalten des Dieselmotors wurde nur eine leichte Scheibe vorgesehen. Dies wäre bei Zahnräderübertragung nicht zulässig gewesen, weil die Zahndrücke nur ganz wenig schwanken dürfen; der Antrieb eines Luftkompressors konnte dagegen fast beliebig ungleichförmig erfolgen.

Kühlung des Kompressors

Eine Kühlung der Zylinderdeckel, wie bei Kompressoren fast allgemein üblich, wäre hier thermodynamisch falsch gewesen. Da auf der Lokomotive zum Kühlen nur Wasser mit 60 bis 100 ° zur Verfügung steht, während die Luft aus dem Freien auch im Hochsommer mit nicht mehr als 25 ° angesaugt wird, so hätte die Kühlung der Saugseite mit Wasser in Wirklichkeit keine Kühlung, sondern eine Heizung bedeutet und den Lieferungsgrad und den Wirkungsgrad der Übertragung verschlechtert.

Auf der Druckseite des Zylinderdeckels hätte die Kühlung mit Wasser ein Abkühlen der Druckluft bedingt und einen Verlust bedeutet, da die Druckluft unmittelbar darauf in den Erhitzer gelangt. Die Zylinderlauffläche zu kühlen, wäre zwar nicht falsch gewesen; eine solche Kühlung hätte aber bei einem so großen und zugleich schnellaufenden Kompressor zu wenig gewirkt und den Verlauf der Verdichtung nur ganz wenig unter die Adiabate erniedrigt.

Dazu kommt noch, daß während der ersten Hälfte des Hubes die Luft noch kalt ist. Wenn also die Kühlung der Zylinder überhaupt wirken soll, so muß man im Kreislauf über Kühlwasser von höchstens 40 ° verfügen. Das führt aber beim Rückkühlen des Wassers durch die Außenluft zu Kühlern von Abmessungen, die sich für eine Lokomotive nahezu verbieten.

Ähnliches wie für die Kühlung der Lauffläche gilt auch für die Kühlung des Kolbens. Trotzdem wurde der Kompressor so gebaut, daß Lauffläche und Kolben gekühlt werden können, weil die von Anfang an vorgeschlagene neuartige Einspritzkühlung, mit der der Kompressor auch ausgeführt wurde, noch nicht erprobt war. Abgesehen von Vorversuchen wurden aber diese Kühlungen nie verwendet.

Die Einspritzkühlung darf man nicht mit dem Betrieb bei sogenannten „nassen" Kompressoren verwechseln; denn die Luft ist am Ende der Verdichtung nicht naß. Das in den Hubraum eingespritzte Wasser wird nicht nur vollständig verdampft, sondern sogar hoch überhitzt. Nach diesem Verfahren[3]), wird nämlich in den Zylinder nur so viel Wasser eingespritzt, als durch die entstehende Verdichtungswärme mit Sicherheit verdampfen kann. Bei Verdichten von 0.95 auf 7 at kann man so im Grenzfalle durch Wassereinspritzen den Exponenten der Verdichtungslinie von 1,41 auf 1,097 erniedrigen. Die Temperatur am Ende der Verdichtung würde dann nur 85 ° betragen. Man kann also auf diese Weise eine sehr viel wirksamere Kühlung erreichen als mit Mantelkühlung, die bei großen Abmessungen und hohen Drehzahlen auf keinen Fall genügt.

Von dem theoretisch möglichen Grenzwert der Einspritzmenge bleibt man aus Betriebsgründen ziemlich weit entfernt; man spritzt nur soviel Wasser ein, daß die Luft beim Austritt aus dem Kompressor 180 ° hat. Die Lokomotive ist ferner den größten Teil ihrer Betriebszeit über nicht voll belastet und bei Teillast wird im Gegensatz zur Dampflokomotive der Druck in den Zylindern verringert. Infolgedessen fährt man im Durchschnitt nur mit 4 bis 5 at Zylinderdruck, wobei erheblich weniger Wasser ausreicht, um zu verhindern, daß die Temperatur der Luft 180 ° überschreitet. Im praktischen Betrieb ist daher der Verbrauch an Einspritz-

[3]) DRP 417 534 Kl. 46 d.

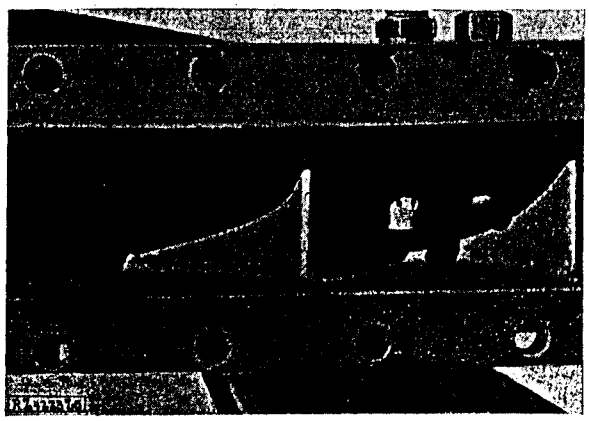


Abb. 5
Druckluftsammelstutzen nach Beendigung sämtlicher Probeläufe. Linke Seite ungereinigt, rechte Seite mit Schaber gereinigt.

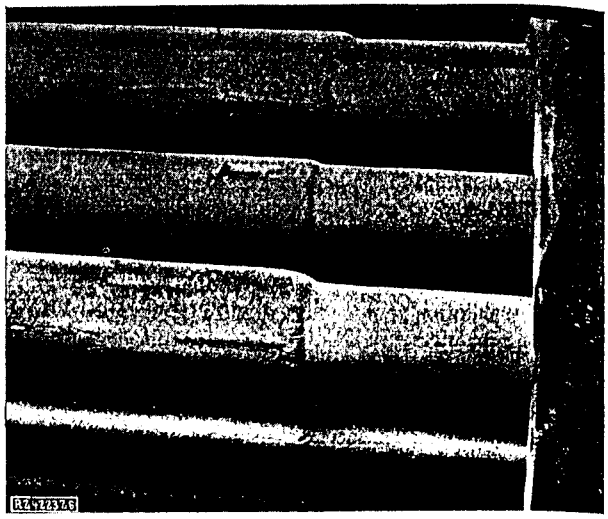


Abb. 6
Blick in den Erhitzer nach Beendigung der Augsburger Versuche. Man erkennt, daß an einzelnen Stellen eine ganz schwache Rußschicht weggekratzt wurde.

wasser so gering, daß man das Verfahren auch in wasserlosen Gegenden anwenden kann. Jedenfalls steht der Bedarf an Einspritzwasser in keinem Verhältnis zu dem Speisewasserbedarf einer Dampflokomotive für die gleiche Anzahl von Tonnenkilometern.

Man hatte zunächst befürchtet, daß Verunreinigungen des Wassers den Kompressor oder die Druckventile verschmutzen und den Betrieb stören könnten. Die Wirklichkeit ist aus Abb. 3 und 4 zu ersehen; sie zeigen ein ungereinigtes Druckventil, das sämtliche Probefahrten und die Abnahmefahrt der Reichsbahn mitgemacht hatte, wobei zum Einspritzen gewöhnliches Speisewasser für Lokomotiven benutzt worden war. In Gegenden mit stark unreinem Wasser kann man das Wasser zur Schonung des Kompressors reinigen. Da der tägliche Wasserbedarf nur ein Hundertstel des Bedarfs einer gleich starken Dampflokomotive beträgt, so verursacht eine solche Anlage nur unbedeutende Kosten und kann, wenn notwendig, leicht von einem Ort an einen andern gebracht werden.

Thermodynamisch betrachtet, ist die Wassereinspritzung beim Kompressor gerade das Gegenstück zur Brennstoffeinspritzung beim Motor. Während der Brennstoff die Temperatur der Luft erhöht und damit das Diagramm entwickelt, verhindert das Wasser die Temperaturerhöhung der Luft, damit das Diagramm möglichst klein wird.

Noch wichtiger als die Wassereinspritzung ist der Erhitzer für die Erzielung eines guten Wirkungsgrades der Übertragung. Er arbeitet im Gegenstrom, und damit man ihn leicht reinigen kann, werden die Auspuffgase durch die Rohre und die Luft um die Rohre herum geleitet. Aus dem gleichen Grunde ist der Erhitzer an der Außenwand der Lokomotive angeordnet. Wie gering die Verschmutzung des Druckluftsammelstutzens und des Erhitzers ist, zeigen Abb. 5 und 6. In Abb. 5 zeigt die linke Seite des Druckluftstutzens den Zustand, in dem sich die Oberfläche nach Beendigung der ausgedehnten Augsburger Versuche befand; die rechte den Zustand, nachdem die Rohre mit einem Schaber gereinigt worden waren, wie man an den Kratzspuren erkennt.

Abb. 6 zeigt ein Ende eines Erhitzerrohrbündels nach der gleichen Betriebsdauer, ebenfalls in ungereinigtem Zustand und teilweise abgekratzt. Die Oberfläche ist von einem ganz schwachen Rußhauch bedeckt, der, wie Messungen bewiesen haben, den Wärmeübergang nicht stört, zumal beim Entwurf des Erhitzers mit einer sehr viel stärkeren Rußschicht gerechnet und die Wärmedurchgangszahl entsprechend niedrig eingesetzt wurde.

[B 4223]

GERMAN STATE RAILWAYS' DIESEL-COMPRESSED AIR LOCOMOTIVE

(*For description see opposite page.*)

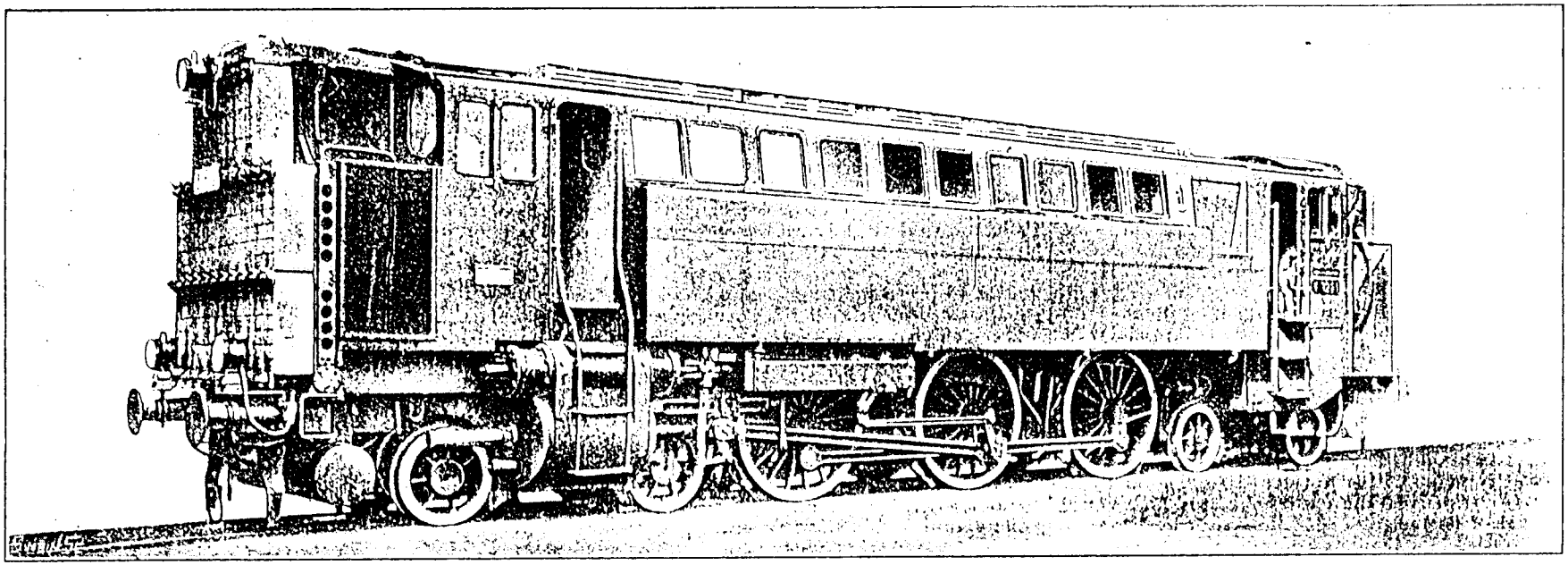


FIG. 1—GENERAL VIEW OF THE LOCOMOTIVE

1200 B.H.P. Diesel-Compressed Air Locomotive for the German State Railways.

In our annual review of locomotive progress during 1929, which appeared in THE ENGINEER for January 3rd, 1930, brief mention was made of the new Diesel-compressed air locomotive, which has been designed and built by the Maschinenfabrik Augsburg Nürnberg A.G. and the Maschinenfabrik Esslingen for the German State Railway Co. A view of the completed locomotive is reproduced on page 486, and it may be recalled that in the official tests carried out in the Stuttgart district in November last, the engine pulled a train weighing 233 tons up the Geislinger Steige gradient of 1 in 43 mostly on curves, at an average speed of over 20 kiloms. per hour.

Some particulars of this locomotive were given in the *V.D.I. Journal*, No. 10, of March 8th last, in an article by Reichsbahnrat Witte and Mr. R. P. Wagner, while in the same *Journal*, No. 12, of March 22nd, Dr. Ing. Jos Geiger, of Augsburg, contributed a further article entitled "Diesel Locomotive with Compressed Air Transmission."

The article which follows has been prepared from some further notes by Dr. Geiger, which have been placed at our disposal by the London representatives of the M.A.N. Company—John Le Boutillier, Ltd., of 13, Rood-lane, E.C. 3. The locomotive is now at the Grunewald railway shops of the Reichsbahn, and very thorough tests are being carried out. It is hoped that an account of the test performance will be given in one of the papers to be read at the forthcoming Power Conference, which is to be held from June 16th to the 25th in Berlin.

At the time the locomotive was ordered, the following position influenced the builders and the railway officials in their decision to adopt compressed air transmission. Up to the time of the placing of the order experience had already been gained with internal combustion locomotives embodying the direct drive, the geared drive, the fluid transmission drive, and the electric drive, while locomotives embodying these different systems had either been built and tested or were then in course of construction. At that time, however, a locomotive of the internal combustion type operating with compressed air transmission had not been built. On many sides the opinion prevailed that such a method of power transmission was valuable on several grounds. Thus, the hyperbolic curve of tractive power for compressed air working approached very closely that for steam and fitted in well. Again, by utilising compressed air, difficult manœuvring operations were avoided, and the driver had only to attend to the regulation of the supply of fuel to the oil engine. Another advantage of the compressed air system, it was held, was that the driver would have to deal with essential parts of the locomotive already familiar to him in steam practice.

On the other hand, there were those who foresaw difficulties, and did not hesitate to prophesy failure. It was said that the efficiency of the compressed air system of power transmission was lower than that of any other system, and it was also suggested that explosions arising from oil in the compressed air might take place, while stoppages could occur owing to the formation of ice on the cylinders in which the air was to be expanded.*

* See *Diesel Power* for February, 1930, page 94.

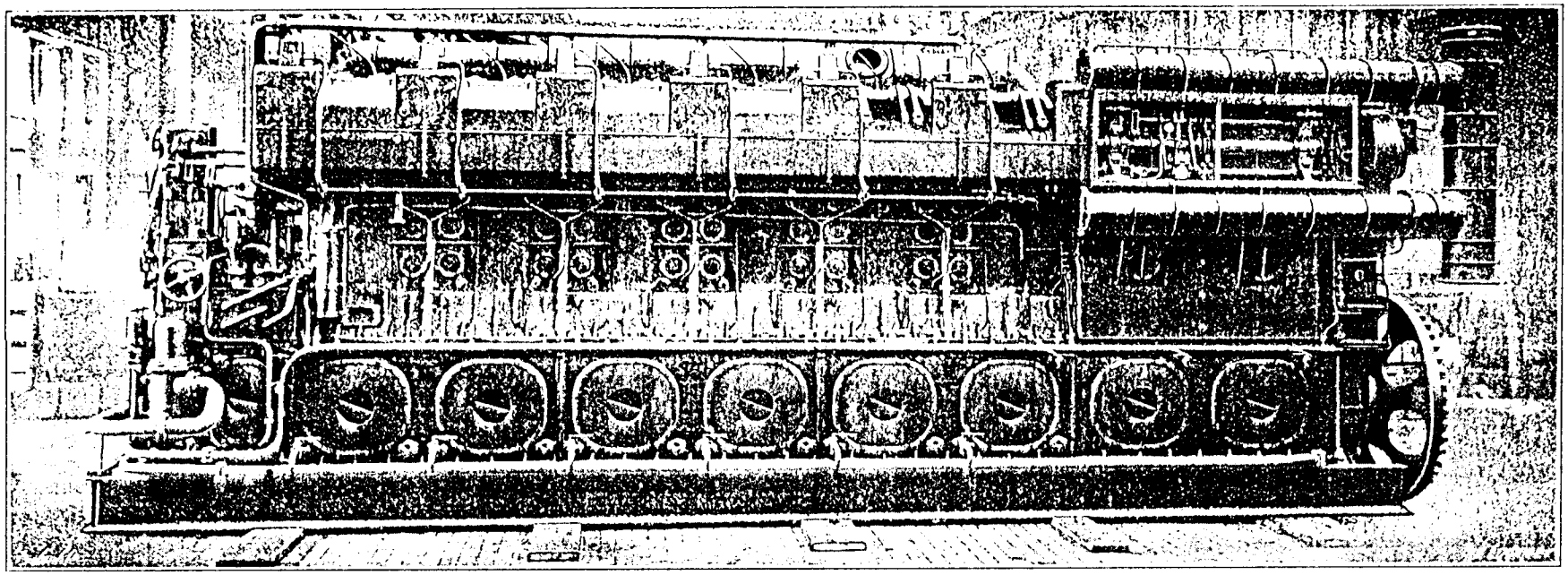


FIG. 2.—M.A.N. 1200 B.H.P. DIESEL ENGINE AND AIR-COMPRESSOR

Such statements were made even after actual experience with the locomotive showed that such happenings did not occur. We are informed that, in fact, the efficiency of transmission with the oil-compressed air system has been demonstrated to be higher than with the oil-electric system, enabling a 12 per cent. saving on the fuel used per ton-kilometre to be recorded at a common speed of 60 kiloms. per hour. There have been no explosions of oily vapour, even although in a works test it was sought to produce such explosions artificially by the introduction of electric sparks.

During the long series of trials which have been carried out, there was at no time any signs of ice formation on the cylinders of the locomotive. On the contrary, when the hand was placed in the air at the exhaust outlet it was quickly withdrawn, since the air, after being expanded to close upon atmospheric pressure, still retained a temperature of about 100 deg. Cent. No difficulties have been experienced with the deposit of dirt from particles of lubricating oil or carbon in the air reheater, or with the clogging of the air compressor valves from like causes. A photograph of two of the air compressor valves which were removed after the completion of all trials is reproduced in Fig. 5. It clearly indicates the comparatively clean state of the valves.

GENERAL PARTICULARS.

In the following table the general particulars of the locomotive and the leading dimensions of the oil engine and air compressor are given. In Fig. 1, on page 486, a general view of the completed locomotive is reproduced, while in Figs. 2 and 3 views of the engine and air compressor on the test bed at the makers' works are given.

Locomotive Particulars.

Type	4-6-4
Tractive effort at driving wheel rims	12,000 kilos.
Diameter of driving wheels	1600 mm.
Diameter of locomotive cylinders	700 mm.
Stroke of locomotive cylinders	700 mm.
Adhesive weight	54,600 kilos.
Weight empty	118,600 kilos.
Weight in working order	124,000 kilos.
Weight of fuel oil carried	2,000 kilos.
Maximum designed speed	80 kilom. per hr.

Oil Engine and Air Compressor Particulars.

Type of engine	M.A.N. four-stroke single-acting	
Number of cylinders	Six	
Bore of cylinders	450 mm.	
Stroke	420 mm.	
	Continuous load.	Short overload.
Designed B.H.P. output	1000	1200
Designed I.H.P. output	1350	1630
Revolutions per minute	400	450

Working air pressure: 6·5 atm. (92·3 lb. per sq. in.) to 7 atm. (99·4 lb. per sq. in.)

Temperature of air at locomotive cylinders: 330 deg. to 360 deg. Cent.

Type of air compressor: Twin-cylinder single-stage double-acting

Diameter of cylinders	640 mm.
Stroke	350 mm.

The oil engine, as shown by our illustration, is of the normal vertical cylinder type and is generally similar to that supplied for the Russian Diesel-electric locomotives, but embodying several improvements in design. The bed-plate is common to the engine and air compressor, which are direct-coupled. A section through one of the compressor cylinders, which we reproduce in Fig. 4, shows the mechanically operated suction valves and the plate-type delivery valves.

Dr. Geiger claims that the speed of the compressor is remarkable since up to the present air compressors dealing with as much as 182 kilograms of air per minute, have only been built for speeds up to 100 r.p.m. The overall efficiency, we learn, is very high, in spite of the large range of compression, in the single-stage cylinders. It was found that equal values were obtained when the volume of air delivered per minute as ascertained by nozzle tests was compared with the calculated swept volume after allowing for re-expansion in the clearance spaces, which fact is itself a good indication of the very small loss by throttling in the suction and delivery of the air through the valves. The compressed air on leaving the compressor passes directly to a reheater, which operates on the contra-flow principle, and by utilising the heat of the exhaust gases raises the temperature of the air to 360 deg. Cent. From the reheater the air passes through the regulator control valve to the two cylinders of the locomotive in which it is expanded to practically atmospheric pressure.

From the illustrations reproduced on page 486, it will be noted that laminated coolers of the fully welded type are arranged at both ends of the locomotive. These coolers serve the circulating water system for the engine jackets and bearings, the piston cooling oil circuits, and the lubricating oil circuits. The compressor is cooled by the direct

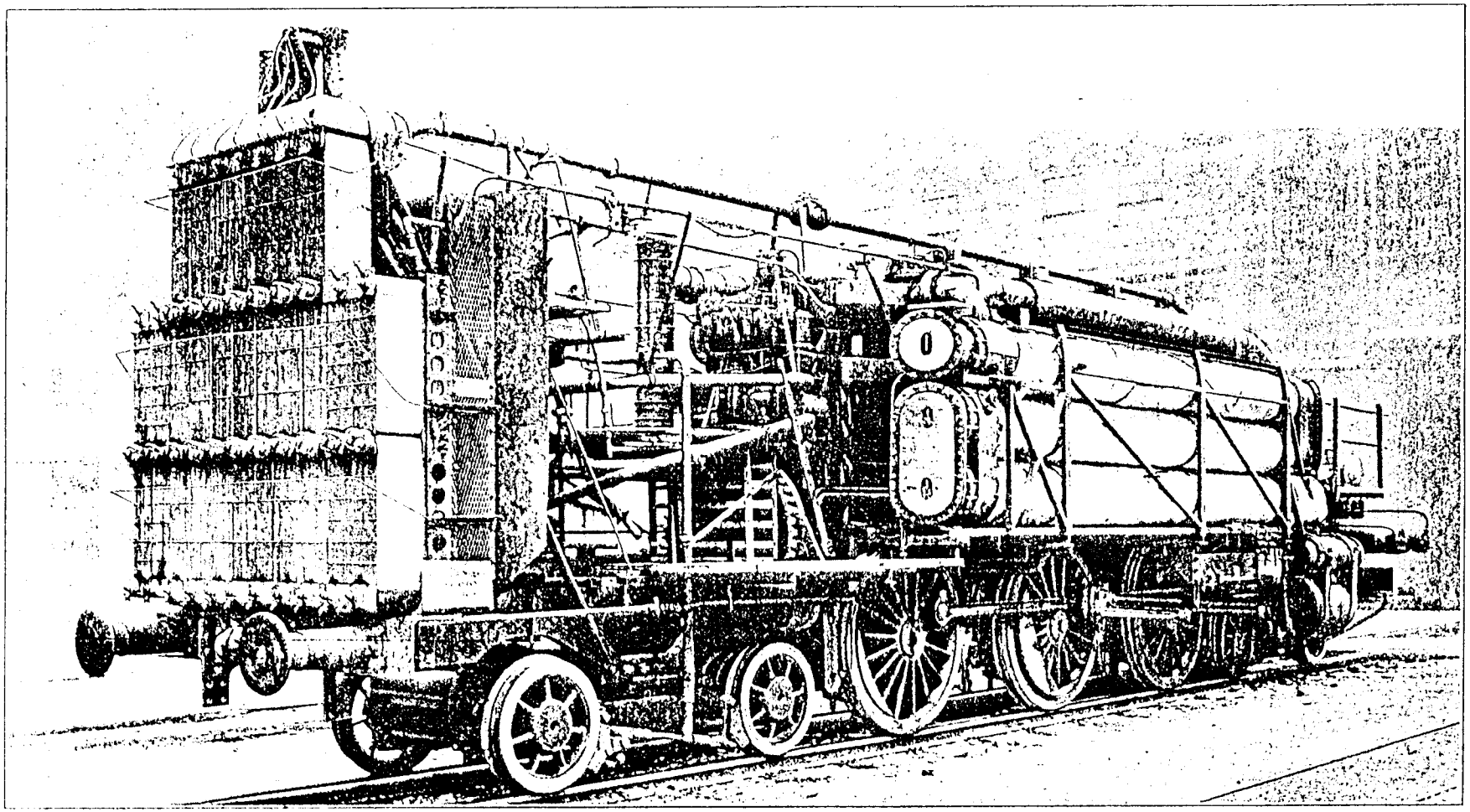


FIG. 3.—VIEW SHOWING THE AIR-COMPRESSOR AND ACCESSORIES

injection of water, which will be referred to later.

Under normal conditions, the natural draught through the coolers is sufficient, but electrically driven fans are provided to meet exceptional cases.

A small direct-driven dynamo provides current for the fan motors and for train lighting, and the compressed air for the brakes is taken directly from the main compressor. The only other auxiliary appliance is an oil-fired boiler for train heating. There are two driving cabs, so that the locomotive can proceed in either direction without the necessity of turning.

Two essentials of the compressed air system of transmission are the injection of water into the compressor for the purpose of cooling the air, and the reheating of the air by the exhaust gases. As will be seen from Fig. 4, the air compressor has neither cooled jackets nor cooled covers. The air is cooled by injecting water in the form of a fine mist into the compression space. For this purpose a special pump with a particular kind of spray nozzle is employed. By the use of water injection it is possible so to cool the air that the compression curve approaches the isothermal line very closely. This could not well be done with surface cooling, especially in the high-speed type of compressor employed. The injection of water into the cylinders also adds weight to the working medium and allows a very much lower entry temperature at the reheater to be employed than would otherwise be possible. This lower entry temperature also enables the heat of the exhaust gases to be better utilised. With the comparatively low temperature of the air leaving the compressor, the delivery valves are rendered more reliable in service and any danger of explosion by the ignition of oil particles is entirely overcome.

THE RUNNING OPERATIONS.

The running of this Diesel-compressed air locomotive is very simple. Immediately before setting out, the oil engine is started up and the air compressor run light with no air circulating through the reheater. As soon as the regulator lever is moved the air compressor is automatically put on load and the pressure of the air delivered rapidly rises so that the locomotive starts as easily as with steam. When running the supply of air to the cylinders is reduced to that necessary for the speed and further adjustments in speed are then made by varying the amount of fuel delivered to the cylinders of the oil engine. When more fuel is admitted the engine increases its speed and more air is delivered by the compressor, with the result that the air pressure rises and increases the speed of the locomotive. The full supply of air is, however, only given to the cylinders when going up the steepest gradients. The driver can also vary the amount of water injected into the air compressor cylinders, but this requires little attention and he can give his full time to watching the track and signals.

It is said that the cost of upkeep is small, and it is held that the normal repair and maintenance facilities as arranged for steam locomotives will suffice. Although some water is required for injecting into the air compressor the amount even under full load conditions is only 1 per cent. of that which would be required by a steam locomo-

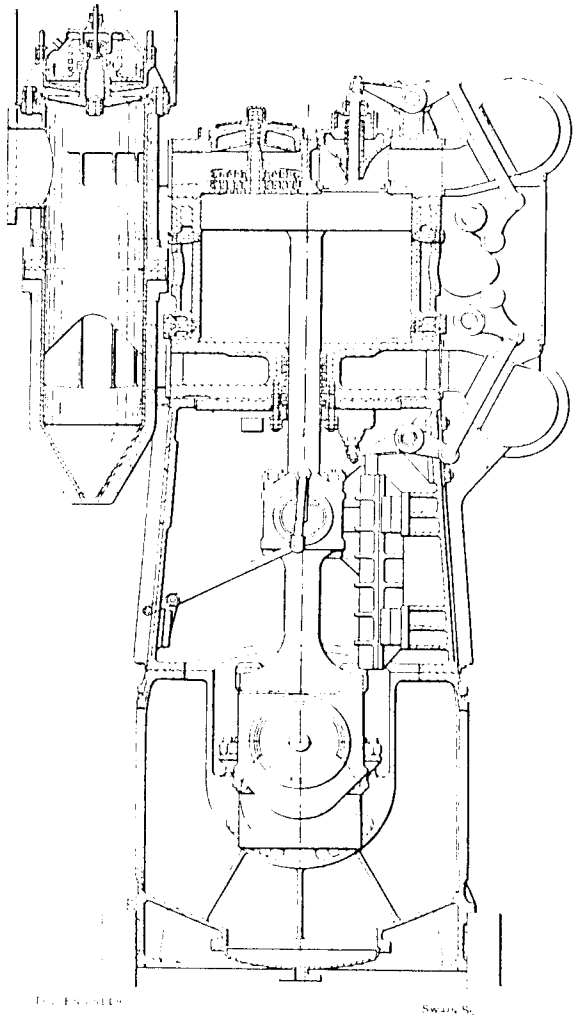


FIG. 4—AIR-COMPRESSOR

tive, and at light loads no water is required. Further details of the test performance of this new locomotive, which it is hoped will be published by the Grunewald railway testing department, will be awaited with interest.

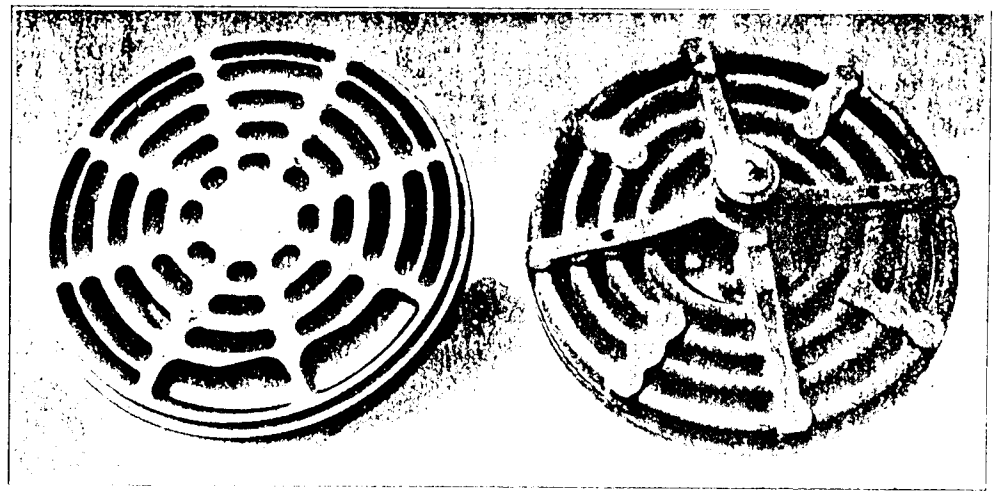


FIG. 5—AIR-COMPRESSOR VALVES

Railway Age 89 (9 Aug. 1930): 280-82.

Diesel Locomotive with Compressed-Air Transmission

Built for the German State Railways—Rated tractive force of 26,455 lb.—Diameter of drivers, 63 in.

By Dr. Ing. Jos. Geiger

A DIESEL 4-6-4 type locomotive with compressed-air transmission was ordered in 1929 by the German State Railways from the Maschinenfabrik Augsburg Nurnberg A. G. and the Maschinenfabrik Esslinger for experimental service and test. This locomotive was placed in service during November. During these road tests, the locomotive hauled a 233-ton train over a line with a ruling grade of 2.3 per cent at an average speed of 12.5 miles an hour. This line had a number of sharp curves, but the maximum power of the Diesel engine was never required at any time during the run. The locomotive has since been on a test plant at the Grunewald shops of the German State Railways. Results of these tests have not as yet been released for publication.

The total weight of the locomotive in working order is 273,500 lb., of which 112,250 lb. is carried on the drivers. Compressed air is supplied to the cylinders, which are 27.56 in. by 27.56 in., at a working pressure of from 92.3 lb. to 99.4 lb., and at temperatures of from 626 deg. to 680 deg. F. The driving wheels are 63 in. in diameter and maximum tractive force 26,455 lb.

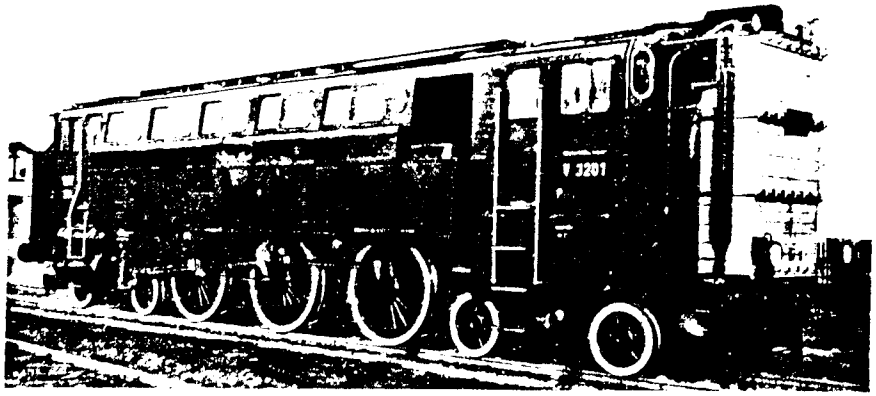
The Diesel engine is an M.A.N. six-cylinder, four-stroke, single-acting power unit, with 17.72-in. by 16.53-in. cylinders. It is designed for a continuous output of 1,000 b.hp. and 1,350 i.hp. at 400 r.p.m. and for short overloads at 1,200 b.hp. and 1,630 i.hp., operating at a speed of 450 r.p.m.

A twin-cylinder, single-stage, double-acting air compressor, with 25.2-in. by 13.78-in. cylinders, supplies compressed air to the locomotive cylinders. The locomotive is designed for a maximum speed of 49.7 miles an hour and carries approximately 580 gal. of fuel oil.

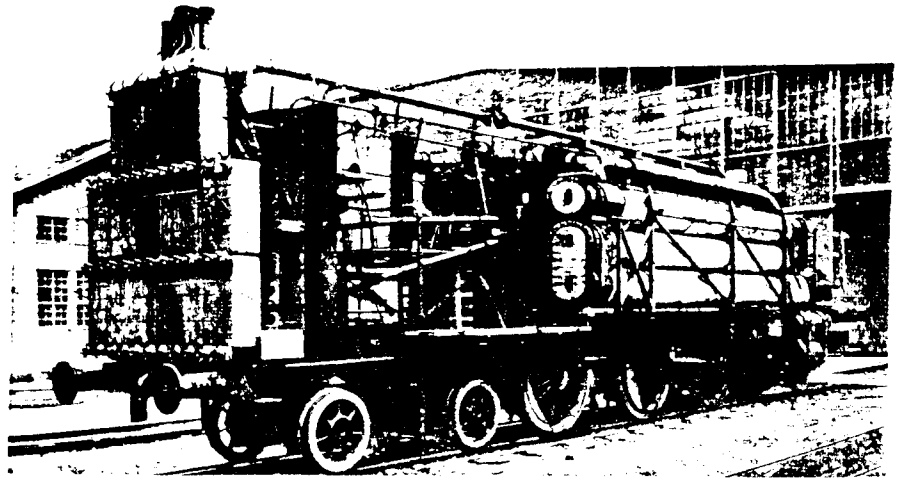
Air Transmission Has Proved Satisfactory

Many engineers specializing in the design and operation of Diesel and compressed-air equipment expressed doubts as to the feasibility of a Diesel locomotive with air transmission. In fact some of these doubts were expressed editorially in several trade papers as late as February, 1930. It is interesting to note, therefore, that the tests of the locomotive which have thus far been made have proved the opposite.

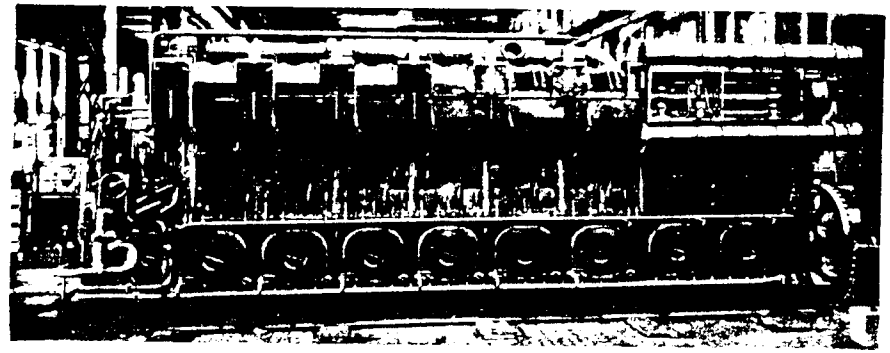
There were a number of reasons for adopting air transmission. The tractive-force curve of a steam locomotive, which has proved so satisfactory in railroad operation, can be duplicated in the case of a locomotive the cylinders of which use compressed air instead of steam. It is also believed that the efficiency of the compressed-air transmission would be an improvement over that obtained with electrical transmission. This has been borne out by the fact that the Diesel-air locomotive uses 12 per cent less fuel oil per ton mile, when operating at a speed of 37.5 miles an hour than a Diesel-electric locomotive developing the same tractive force and operating at the same speed. Contrary to



Diesel-Air 4-6-4 Type Locomotive Built by M. A. N. for the German State Railways



The Locomotive After the Installation of the Air Compressor and Accessories



The M.A.N. 1,200 B. Hp Diesel Engine and Air Compressor

the expectations of many, oil explosions have not occurred even in the test plant when electric sparks were purposely introduced into critical parts of the equipment to create oil explosions. No ice formations have occurred during any of the numerous test runs of the locomotive. The exhaust temperatures average 210 deg. F. even when the compressed air is expanded to nearly atmospheric pressure. The air superheaters have not become clogged with deposits of lubricating oil or soot. Neither has the operation of the compressor valves and other parts of the equipment been interfered with by such causes.

The Diesel Engine and Air Compressor

The Diesel engine is of the normal vertical-cylinder type and is somewhat similar to those used on the Diesel-electric locomotives built for the Russian Government in 1925, but embody several improvements in design.* The bed plate of the Diesel-engine on the Diesel-air locomotive serves for both the engine and air compressor which are directly coupled. The normal speed of 400 r.p.m. of the air compressor is unusually high for a compressor of this size. Air compressors of this capacity—about 5,000 cu. ft. of free air per min.—are built for speeds of approximately 100 r.p.m.

The volumetric efficiency of the compressor is high in spite of the high speed and the high compression ratio for a single-stage compressor. Comparing the air quantity, measured by an orifice, with the piston displacement less re-expansion from the clearance space, one finds practically the same value, a proof that the losses through the suction and discharge valves must be extremely small.

The compressed air reaches the superheater by the shortest possible route, where it is superheated to 680 deg. F. in counter flow by the exhaust gases of the Diesel engine. The air flows from the superheater through a regulating valve to the two locomotive cylinders. Front and rear radiators of the laminated type recool the cooling water, the piston cooling oil and the bearing lubricating oil. These radiators are of welded construction. Electrically-driven fans are installed in order to increase the cooling effect of the radiators, but they are not needed for normal operating conditions.

Auxiliary Equipment

A generator, directly connected with the Diesel engine, furnishes the current for the lighting as well as for the fan motors. The Diesel engine also drives a compressor for the air-brake equipment. The main compressor can also supply this air. An oil-fired boiler is installed on the locomotive which is large enough to furnish heat for the train. Facilities for fuel and water supply have been provided on the locomotive.

The locomotive has an operating cab for the engineman, both front and rear, and it is therefore not necessary to turn the locomotive.

The two principal features responsible for the success of the compressed-air transmission are the water injection into the air compressor, and the superheating of the compressed air by the exhaust gases.

The compressor works, for well-considered reasons, without the normal cooling of the cylinders and cover walls. A separate pump supplies a fine spray of water through nozzles into the compressor cylinder. This makes it possible to get a compression curve which is a close approximation to the isothermal. This could not be obtained with surface-cooling, on account of the high rotative speed necessary for the locomotive. The water injection increases the weight of the working medium and, on account of the lower compression end temperatures, allows a better utilization of the exhaust heat of the Diesel engine. The safe operating of the discharge valves is assured by the lower compression temperatures.

The water injection into the compressor is the reverse of the fuel injection into the Diesel engine. While it is desirable in the latter to obtain a temperature rise through combustion of the fuel and thereby increase the area of the indicator cards, the object of the compressor-water injection, is a lowering of the compression temperature in order to get the smallest possible area of the indicator card.

The operation of the locomotive is simple. The compressor is started by moving the regulating-lever to operating position. It is under no load until the locomotive has started. There is no compressed air in the superheater. The air pressure rises quickly and the locomotive can be set in motion as quickly as a steam locomotive. The cut-off of the locomotive cylinders can be reduced after starting. Further regulation of the speed is performed by regulating the amount of fuel injected into the Diesel engine. If the supply of fuel oil is increased, the engine runs faster and the compressor delivers more air, the air pressure rises and with it the speed of the locomotive. It is only necessary to increase the cut-off on very steep grades. The amount of water injected into the air compressor can also be regulated by the engineman, but does not need special attention. The engineman is free to concentrate his attention on handling his train.

Since the fuel consumption is low, it is possible for the Diesel-air locomotive to operate long distances without being required to stop for water and fuel.

* A description of the Russian Diesel-electric locomotives appeared in the January 31, 1925, issue of the Railway Age, page 321.

Cost of Storage-Battery, Compressed-Air, and Gasoline-Locomotive Transportation

May, 1933 — Engineering and Mining Journal Vol. 134, p. 191-194

Morris J. Elsing

Storage-battery locomotives are used as an auxiliary to trolley-locomotive transportation or as the sole means of mechanical hauling. When first introduced they were large and cumbersome; they are now small, compact, and flexible in operation. The smaller models can be transported from level to level on the mine cage, thus adding greatly to their efficient use. These small models are replacing animal haulage, and are also a competitor of the smaller units of trolley locomotives.

A brief review of the more important data relative to transportation by this system is given for several widely scattered mines:

Hanover Bessemer, Fierro, N. M., I.C. 6301—Seven-car trains are hauled by 5-ton storage-battery locomotives equipped with 80-A Edison cells. Cars, of the Griffith bottom-dump type, have a capacity of 5 long tons. Ore chutes are equipped with over- and undercut arc gates. Ore is trammed through the Union Hill adit to a Ding's magnetic cobbing plant. Costs are given in Table I.

Cleveland-Cliffs, Ishpeming, Mich., "Min. & Met," March, 1927—Storage-battery locomotives haul trains of cars each with a capacity of 2.5 long tons or 2.8 short tons. Tramming distance is 1,500 ft., and 50 cars, or 140 short tons, are hauled per motor-shift. The train crew consists of a motorman and a helper. The cost of operating the storage-battery locomotive per day is as follows: Locomotive depreciation and repairs, $1.21 per day; battery depreciation and repairs, $2.02; power, 20 kw.-hr. at 1.5c., $0.30; motorman, $4.60; helper, $4.15; total, $12.28 per day. On this basis, storage-battery locomotive transportation costs 8.8c. per short ton for a tram of 1,500 ft., or a rate of 31c. per ton-mile.

Alaska Gastineau, Alaska, A.I.M.E., Vol. 63—When this mine was operating between 1915 and 1918, Granby-type automatic 4-ton side-dump cars were used. Track rails were 35 lb., and the gage was 26 in. Six-ton Baldwin-Westinghouse storage-battery locomotives with Edison cells hauled 10-car trains. The train crew consisted of a motorman, two chute punchers, and one mucker. Average amount hauled per train-shift was 489 tons. The distance averaged about 600 ft. Cost of tramming per ton, 1915-18, was as follows: Labor, $0.0381; power, $0.0002; maintenance equipment and track, $0.0146; general underground expense, $0.0105; general mine expense, $0.0032; total, $0.0666 per ton.

United Verde, Jerome, Ariz., A.I.M.E., Vol. 66—Three-ton Baldwin-Westinghouse storage-battery locomotives were used. Ore, from stopes on the 1,650 level, was trammed an average distance of 200 ft. to transfer raises. When hauling 215 tons per shift, the total cost per ton was as follows: Labor (one motorman, two loaders), $0.084; power (25 kw.-hr. per shift), $0.004; depreciation on motor equipment, $0.006; repairs and inspection, $0.002; total, $0.096 per ton.

Hauling waste to the stopes an average distance of 350 ft., up a 0.4 per cent grade, including loading and dumping, cost $0.153 per ton. Approximately 135 tons was hauled per motor-shift.

Butte & Superior, Butte, Mont., A.I.M.E., Vol. 68; also "M.&S.P.," Nov. 26, 1921 — Costs per car of ore hauled in 1919 by a 3.5-ton Jeffrey storage-battery locomotive at the Black Rock mine were as follows: Power, $0.004; repairs to locomotive, $0.032; motorman and helper, $0.069; total, $0.105 per car hauled. Cars hauled totaled 605,372. Cars of waste hauled numbered 132,415; average haul of a car of ore was 800 ft.; and average haul of a car of waste, 747 ft. Because of heavy ground caused by settlement of stopes and sills in the wide orebodies, small cars, 14 to 16 cu.ft., or 0.8-ton capacity, were used. Cost on the above basis was about 13c. per ton for an 800-ft. haul.

Anaconda, Butte, Mont., A.I.M.E., Vol. 68—In 1922, the standard type of locomotive had a 3.5-ton chassis and was equipped with 105 Edison A-5 cells. Average length of haul was 1,500 ft. Average duty of a locomotive in 8 hr. was the hauling of 122.5 loaded cars and the returning of the empties. Capacity of the cars was about 1,800 lb.

Cortez, Cortez, Nev., I.C. 6327—Distance from the ore pocket on the adit level to the portal of the adit is 3,200 ft. Hauling on this level is done with a 3.5-ton storage-battery locomotive. A fully charged battery will handle 45 to 50 cars in a shift without recharging. Cars are of the gable-bottom, side-dump type, having a capacity of 50 cu.ft. or 3 tons of ore. A train consists of six cars and is handled by a motorman and a helper, who load the cars and dump them at the mill. They also handle all material and supplies taken into the mine. The motorman receives $5.75 per day and his helper $5.25. In 1929, 43,806 tons was produced. On this basis the labor cost of tramming is 7.7c. per ton, or 12.7c. per ton-mile.

Central Eureka, Mother Lode, California, I.C. 6512—Total underground tramming distance from the Old Eureka to the Central Eureka shaft is 1,800 ft. Ore is trammed in trains of six 1-ton side-dump, rocker-type cars drawn by a 1.5-ton, 3.8-hp. storage-battery locomotive. Ore chutes are provided with steel arc gates. The motorman receives $5 per shift and the helper $3.75. When loading and tramming 150 tons per shift the average cost for labor is 5.8c. per ton, or at the rate of 17.0 per ton-mile.

Portland, Cripple Creek, Colo., A.I.M.E., Vol. 72—Three-ton storage-battery locomotives hauled 16-cu.ft. mine cars with a capacity of 1,500 lb. The longest haul was 3,500 ft. Two contractors were paid 7 or 8c. per car for loading, hauling 2,500 ft., and dumping into shaft pockets. Upkeep costs were small. Cost of labor for hauling was about 21c. per ton-mile.

Colorada, Cananea, Son., Mexico, I.C. 6247 — Waste fill is trammed from a waste chute on the 700 level, an average distance of about 400 ft., by 2.5-ton storage-battery locomotives and six 1-ton cars. An average of 65 tons is handled per motor-shift, but motors can handle as much as 100 tons when required to do so.

Pilares, Nacozari, Son., Mexico, I.C. 6307—Storage-battery and trolley locomotives handle waste and ore on different levels. Cars of 22- and 33-cu.ft. capacity, rocker-dump type, rated at 1 ton and 1.5 tons, are used on levels below the 700. Sixteen-pound rails are laid on all levels except the 700 main-

Table I—Haulage Cost Per Long-Ton-Mile Hanover Bessemer Mine, 1929

	Labor	Supplies	Repairs	Power	Depreciation	Total
Chute operation	$0.026	.....	$0.013	.....	.....	$0.039
Locomotive haulage	0.066	$0.001	0.029	$0.009	$0.012	0.117
Track maintenance	0.002	0.006	.....	.....	.....	0.008
Car maintenance	0.011	0.005	0.001	.....	.....	0.017
General	0.006	.....	.....	.....	.....	0.006
Total per long-ton-mile	$0.111	$0.012	$0.043	$0.009	$0.012	$0.187
Total per short-ton-mile	0.099	0.011	0.038	0.008	0.011	0.167

This is one of a series of articles on the cost of metal mine transportation in the United States.

haulage level. The motor-haulage crew consists of two men on contract, who load at the chutes, haul, and dump the ore at the main ore dumps at the Guadalupe shaft. Costs of transportation per ton-mile by both types of locomotives are: Trolley—1929, $1.11; 1928, $0.95; 1927, $0.92; storage battery—1929, $0.63; 1928, $0.71; 1927, $0.99.

Matahambre, Matahambre, Cuba, I.C. 6145 — Small storage-battery locomotives haul six to eight 20-cu.ft., end-dump cars an average distance of 1,200 ft. Loading is done from chutes equipped with arc gates. Average duty for a crew of a motorman and helper, per 8-hr. shift, is 100 to 150 tons. The motorman receives $2.25 and the helper $2. Labor tramming cost is 3.4c. per ton.

Table II—Mine Haulage Costs Per Ton-Mile of Ore Hauled, 1916-17-18, Storage-Battery Locomotives

Location	Ariz.	N.M.	Ariz.	Mont.	Alaska	B.C.
Weight locomotive	4 Ton	3 Ton	3 Ton	3 Ton	6.5 Ton	3.5 Ton
Capacity car, lb.	2,000	2,000	1,800	1,500	6,000	4,000
			Cents			
Power	1.6	1.6	2.3	3.3	1.5	3.7
Labor and material	29.5	35.8	19.8	60.0	....	36.8
Total operating	31.1	37.4	22.1	63.3	....	40.5
Locomotive maintenance	0.4	3.7	....	....	3.2	....
Car maintenance	6.1	11.1	....	....	....	....
Track maintenance	5.8	23.2	....	....	....	....
Total maintenance	12.3	38.0	13.3	10.7	....	5.3
Total cost	43.4	75.4	35.4	74.0	62.2	45.8

Miscellaneous Costs — The costs in Table II were furnished me by the Westinghouse Electric & Manufacturing Company. Part of the data have been summarized in Table III.

Summary — In the costs presented for hand tramming and for trolley and storage-battery transportation, an inconsistency may seem apparent to the uninitiated in a cost of 7c. per ton for loading hand-tram cars, whereas the total cost of transportation, including loading, for the other methods is less than this amount. However, as previously mentioned, the loading cost per car does not increase in a proportional ratio to the size of the car. The spotting of a car under the chute mouth, the opening of the door, the barring necessary to start the flow of ore, and, finally, the closing of the door are the same, regardless of the size of the car. When the flow of ore has started, only a few seconds longer is needed to fill a 10-ton car than a 1-ton car. Likewise, to load a 10-car train of 1-ton cars does not take ten times as long as to load 10 individual cars each of 1-ton capacity. In the former case, each operation can be more efficiently done. When the flow of the ore is started by the loading of the first car, subsequent cars of the train can be more easily loaded because the ore in the chute has been thoroughly broken up. In general, the continued drawing of ore prevents packing and consolidation, which is the tendency in chutes that are infrequently drawn.

Another factor that lowers the loading cost where large tonnages are handled by mechanical haulage is that ore chutes and loading pockets are large, resulting in a freer flow of ore. Chute gates are large and of efficient design. In most large operations the ore has already been drawn from stope chutes, where bulldozers have prepared it for subsequent drawing from transportation raises by breaking up large pieces and removing timber or drill steel, all of which often give trouble in the smaller hand-tramming chutes. In short, conditions for chute drawing where mechanical transportation is employed on a large scale are made as perfect as possible, and this accounts for the great difference in loading costs when compared with hand tramming.

Storage Battery vs. Trolley Locomotive Transportation—Briefly to review the opinions of various operators from different parts of the United States relative to installation and operating costs of both systems at the same mine is of interest. In referring to conditions at Butte, Mont., C. W. Woodward has said (A.I.M.E. Vol. 68) that the cost of trolley wire and track-bonding installation on the long hauls is almost equal to a set of storage batteries for a locomotive. Hence there is little difference in cost between a trolley and storage-battery locomotive installation. Cost of maintenance of the two types of installation has been in favor of the latter, because of the labor necessary to keep the trolley wire in alignment with the rails, because of movement of ground in several mines and the constant repairing of guard strips over the trolley wire.

George C. Newton (*Engineering and Mining Journal*, Dec. 8, 1930) makes a careful analytical annual cost comparison of the two systems: *Trolley System* —Interest, 6 per cent on $15,000, $900; depreciation, $2,400; operating costs, $10,560; total, $13,860. *Storage-Battery System*—Interest, 6 per cent on $10,000, $1,140; depreciation, $3,700; operating costs, $8,780; total, $13,620.

He further states that "The cost of power for the trolley system of haulage is generally assumed to be lower than that for the storage-battery system. Exactly the reverse is true, however. A material difference is in favor of the storage-battery system." He then points out that charging can be done largely at off-peak periods, resulting in a considerable saving in the power costs.

According to Everard Leland, in data already cited, the experience at Nacozari has proved that transportation by storage-battery locomotives is more economical than by trolley locomotives. In this instance, as well as in others where similar results obtain, the tramming distance is generally short.

The obvious conclusion, based on the data presented, is that each of these methods has its own particular field, and that when used in that field lower costs of transportation result. The storage-battery locomotive is most advantageously used in the short haul; and, in general, the worse the underground conditions the greater are its advantages over the trolley system. In haulage drifts in moving ground, only with the greatest difficulty can trolley wire be maintained in proper alignment. Heavy ground makes extremely desirable a reduction in size of drifts, because the smaller the drift the less will be the difficulty of keeping it open. For this reason, in mines with much heavy ground in the stoping areas, small cars are used, with the idea that the added cost of transportation is more than offset by the lesser cost of upkeep and repairs of the haulageways. The safety rules of mines and the mining laws of some states prohibit the use of trolley wires in low drifts, and require that they be provided with adequate guards at loading chutes. The added difficulty of repair work, to both drifts and chutes in which trolley wires have been strung, is still another reason for the use of the storage-battery locomotive. A trolley locomotive can, of course, be equipped with an extension reel, so that short runs can be made into areas where ground conditions are

Table III—Cost Data of Storage-Battery Locomotive Transportation

	Size of Cars, Tons	Tons per Train	Tons per Shift	Length of Haul, Ft.	Cost per Ton, Cents	Date	Remarks
Hanover Bessemer	5.5	40	...	....	9.1(a)	1926	Labor only
Hanover Bessemer	5.5	40	...	....	16.7(a)	1929	Incl. deprec.
Cleveland-Cliff	2.8	..	140	1,500	8.8	1926	Incl. deprec.
Alaska Gastineau	4.0	40	489	600	6.7	1918	Incl. deprec.
United Verde	1.0	..	215	200	9.6	1919	Incl. deprec.
United Verde	1.0	..	135	350	15.3	1919	Incl. deprec.
Butte & Superior	0.8	..	...	800	13.0	1919	Incl. deprec.
Anaconda	0.9	..	110	1,500	10.0	1921	Estim. labor
Cortez	3.0	18	142	3,200	7.7	1929	Labor only
Central Eureka	1.0	6	150	1,800	5.8	1930	Labor only
Portland	0.8	..	100	2,500	10.0	1920	Labor only
Colorada	1.0	6	65	400	7.0	1929	Labor only
Pilares	1.0	..	...	1,500	63.0(a)	1929	Incl. deprec.
Matahambre	1.0	7	125	1,200	3.4	1928	Labor only

(a) Per short-ton-mile.

bad, but such a method applies only to special circumstances.

In mines where numerous levels produce comparatively small tonnages a small storage-battery locomotive can be transferred from level to level. Under such conditions it becomes a very efficient means of transportation. If the tonnage on any given level comes from many scattered ore chutes, it provides the most economical means of gathering and delivering ore to the shaft pockets or to loading pockets, from which it may be transported by trolley locomotives a mile or more to the mill.

Referring now to trolley-locomotive transportation costs, one finds that where large tonnages are handled for distances of a mile or more the ore can be transported for 5c. per ton-mile; such a cost is the rule rather than the exception. Reference to Table III will show that transportation costs with storage-battery locomotives are several times this amount. From all data submitted, the trolley system of transportation is obviously still supreme in the field of the long haul where large tonnages are transported.

Compressed-Air Locomotive Haulage—Use of the compressed-air locomotive as the motive power for metal-mine haulage is not widespread. It is now used at the Inspiration and Ray mines, Ariz., and at the Homestake, S. D. Its use has been confined to the larger mines, and apparently its adoption has not been found as satisfactory as at first anticipated. In discussing this subject, A. C. Stoddard, of Inspiration (Bureau of Mines I.C. 6169), says:

"Although the efficiency and economy of electric haulage were recognized, the question of its safety was considered debatable, especially under the intensive loading of cars and movement of trains that the company anticipated. For considerable distances haulage was to be through drifts in which loading chutes were spaced at 25-ft. intervals on both sides of the drift. The guarding of the trolley wire at the chutes and the protection of men while loading cars were considered such a serious problem that it was decided to adopt a haulage system in which the hazard of the trolley wires was eliminated.

"In discussing this type of haulage it can be said, of course, that whatever danger existed from the trolley wires was eliminated, but dangers and difficulties not at first thought of were introduced. A reciprocating machine is not so easily controlled as a rotating machine; therefore, air locomotives require more careful handling than electric motors. Often when given a full head of air there is a decided jump upon starting, which is dangerous. The couplings at the charging stations break at times and allow the swiveled connections to fly about with terrific force. Finally, the speed of trains cannot be controlled so easily as with an electric motor.

Table IV—Air-Locomotive Haulage Costs in Cents Per Ton-Mile at Miami, Ariz.

	1918	1919	1920	1923	1924	1925	1926	1927	Average
Locomotive supplies	0.053	0.106	0.127	0.132	0.131	0.197	0.188	0.251	0.148
Locomotive repairs	0.386	1.684	0.706	0.592	0.631	1.780	0.977	0.931	0.961
Air line maintenance	0.295	0.211	0.177	0.201	0.062	0.128	0.107	0.141	0.165
Compressor maintenance	0.260	0.402	0.256	0.633	0.393	0.261	0.111	0.193	0.313
Power	1.063	1.891	1.481	1.902	1.569	2.127	1.567	1.573	1.647
Total	2.057	4.294	2.747	3.460	2.786	4.493	2.950	3.089	3.234
Tons hauled (000 omitted)	5,117	4,186	5,091	5,128	5,154	5,051	4,227	2,463	4,552
Average distance, miles	0.553	0.414	0.458	0.435	0.376	0.454	0.649	0.655	0.486

"An air locomotive has one advantage that might be overlooked—it can still pull cars through drifts in heavy ground where clearance has been considerably reduced; while with trolley locomotives, allowance must be made for the trolley wire. Of course, it may be said that a storage-battery locomotive has the good points and none of the failings of an air motor. This can now be granted, but the storage-battery locomotive was in its infancy when Inspiration adopted the air motor."

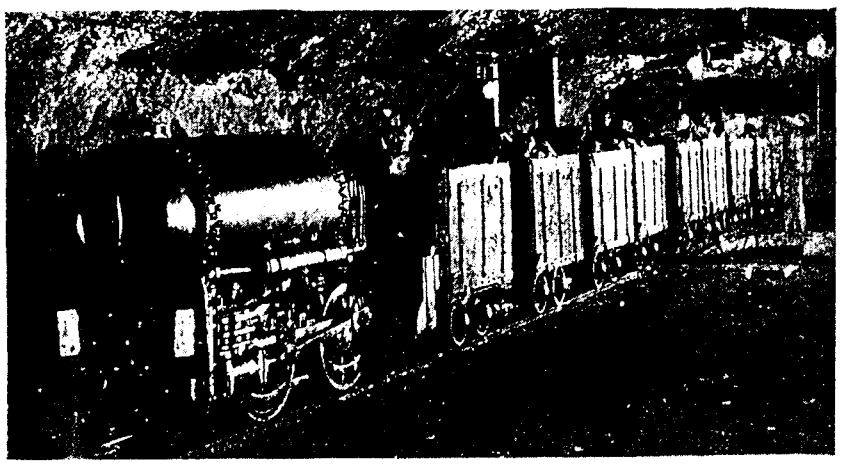
The few costs available for compressed-air locomotive transportation are given in the following:

Ray, Ariz., I.C. 6167—The standard ore car used in this mine has a capacity of 103 cu.ft. Average load is 4.6 dry tons. Haulage is by means of 8-ton compressed-air locomotives with a drawbar pull of 3,000 lb. The locomotives are charged at conveniently located stations to a pressure of 900 lb. per square inch, the operation requiring about one-half minute. The track is of 35-lb. rails in the laterals and 45-lb. rails in the main haulage, laid to 30-in. gage. Trains consist of 20 to 25 cars. They are brought from the stopes to the main haulage by the service locomotives, and from there hauled to the tipple by the main-line motor. Length of this haul averages about 3,000 ft. The train crew on the main line consists of a motorman and one brakeman. In the sublevel blocks the crew consists of a motorman, a brakeman, and a chute blaster. The chute blaster loads the cars. At the tipple the train is turned over to a tipple motorman and his brakeman, and an empty train picked up and taken back to the drawing section. Motor chutes are of timber construction with chute boards held in cleats. Cars are dumped by the three-car electrically driven tipples. Time of dumping a train of twenty cars is about twenty minutes. Cost per ton of loading, hauling and dumping in 1928 (including operation of tipples) was: Labor, $0.059; timber, $0.001; power, $0.007; machine shop, $0.014; miscellaneous, $0.010; total, $0.091 per ton.

Inspiration Copper, Miami, Ariz., M.C.J., Feb., 1928—Twenty 5-ton box-type cars hauled by H. K. Porter 10-ton compressed-air locomotives. Gage of the track is 30 in.; air pressure is 1,000 lb., and the speed of trains is 8 miles per hour. With one charging, a one-way 3,000-ft. trip can be made. A five-car tipple unloads cars at the shaft. The costs given in Table IV do not include operating labor. The train crew consists of a motorman and two helpers.

Homestake Mining, Lead, S. D., A.I.M.E., Vol. 72, "E.&M.J.," July 17, 1926 — Underground transportation is done by 3.5- and 5-ton compressed-air locomotives. For surface transportation, 7.5- and 14-ton locomotives are used. The 14-ton locomotive hauls a train of 32 4-ton cars, or a total of 128 tons per trip. Maximum underground haul is 45 1-ton cars. Mine track gage is 18 in., and 40-lb. rails are used on the main haulageways.

Compressed-air locomotive transportation is becoming obsolete. According to the U. S. Bureau of Mines, 11,986 trolley, 2,294 storage-battery, and 85 compressed-air locomotives were in use in 1924 in the soft-coal mines of the United States. Between 1918 and 1922 the use of storage-battery locomotives increased by 300 per cent, and that of trolley locomotives by 23 per cent;



Compressed-air haulage at the Homestake

whereas during the same period a sharp decrease occurred in the use of the compressed-air locomotive. The storage-battery locomotive of the present day offers all of the advantages possessed by the compressed-air locomotive, with added safety of operation and all at a cost considerably less.

Gasoline Locomotive Transportation—This discussion of mechanical underground transportation would not be complete without mention of the gasoline locomotive. In 1924, 226 gasoline locomotives were employed in the soft-coal mines of the United States. This method of transportation has never been popular in metal mines, as its use is possible only where ventilating conditions are ideal. This limits its application to tunnels and to shallow mines which have many surface openings.

H. I. Young states (A.I.M.E., Vol. 57) that in the Joplin district the 6-ton gasoline locomotive is the most popular and gives no trouble with regard to ventilation. He further states that in four months of 1917, 136,272 tons was hauled an average distance of 1,750 ft. by gasoline locomotives. Average ton costs were: Engineer, 1.4c.; brakeman, 1.2c.; oil for locomotive, 0.2c.; gasoline, 1.1c.; repairs, 1.5c.; car couplers, 1.6c.; total, 7.0c. per ton.

Cleveland, Hazel Green, Wis., "E.& M.J.," July 11, 1914—In 1913 at this Wisconsin lead-zinc mine 4-ton Whitcomb gasoline locomotives were used. Gage of the track was 18 in., and the hauls were generally short. During 1913, 123,150 tons was hauled. Distance traveled was 6,970 miles, half of which was with load and half empty. Operating costs in cents per ton comprise labor, 1.5c.; maintenance and supplies, 0.5c.; total operating, 2.0c. per ton.

85-Mine, Lordsburg, N. M., "M.&S.P.," April 5, 1919—Ore is hauled from the shaft ore pockets to the ore bins, a distance of 1,320 ft. About 500 ft. of this distance is underground. Three-ton Plymouth gasoline locomotives hauled six 2.5-ton, V-bottom, side-dump cars. During twelve months of 1917-1918 118,859 tons was hauled at the following cost per ton: labor, 2.9c.; gas and oil, 0.8c.; maintenance, 0.4c.; total, 4.1c. per ton. This is at the rate of 16.4c. per ton-mile of useful haul. According to Information Circular 6413, this method of transportation is still satisfactorily employed.

Hartley, Tri-State District, I.C. 6656—Ore is transported on the surface from the shaft ore bins to the crushing plant by a 7-ton gasoline locomotive. The track is 36-in. gage, and 35-lb. rails are used. Six 8-ton Granby-type cars make up a train, which is loaded by the motorman, without leaving his cab. The train is dumped automatically as the train advances over an ore pit at the mill. During a period of six months 121,762 tons was hauled an average distance of 2,600 ft. at the following cost: Labor (operator), 0.76c. per ton; labor (on track), 0.04c.; repairs to locomotives and cars, 0.05c.; gasoline, 0.27c.; oil and grease, 0.03c.; total direct costs, 1.15c.; flagman on highway crossing, 0.45c.; depreciation on cars, 0.27c.; depreciation on locomotive, 0.24c.; total indirect costs, 0.96c.; total costs, 2.11c. per ton. On this basis the direct cost is 2.3c. per ton-mile, and the total charges are 4.3c. per ton-mile.

Nevada Massachusetts Mines, Mill City, Nev., I.C. 6284 — Ore is hauled from the mine bins to the mill by an 8-ton gasoline locomotive. One man loads and dumps cars, operates the locomotive, and looks after the equipment. Cars, with a capacity of 67.5 cu.ft., or about 5 tons each, are of the cable-bottom, side-dump type, equipped with roller bearings and chilled wheels 14 in. diameter. A train consists of five cars. Track is of 30-lb. rails laid on an average grade of 4 per cent in favor of the loaded trains. The steep grade on the surface track is due to the nature of the topography and the location of the mill. Ties are 4x6 in., 4 ft. long, spaced on 2-ft. centers.

Cost of transporting ore from the mines to the mill is as follows: Labor (one man at $6 per day, $6 per day; gasoline per day, $3; oil and other expenses, $1; total, $10 per day. Average distance of haul, 2 miles; tons hauled per day, 142; ton-miles per day, 284; cost per ton-mile (without depreciation), 3.5c.

Trojan, Lead, S. D., "E.&M.J.," Oct. 28, 1922 — Gasoline locomotives were used in transporting ore on surface a distance of 2,000 ft. Eighteen 1.5-ton cars made up a train. Production was at the rate of 400 tons per day. Cost of transportation was 6c. per ton, or at the rate of 15.8c. per ton-mile. The costs mentioned are not entirely typical of transportation by gasoline locomotive. A cost of less than 5c. per ton-mile is not uncommon in coal mines. However, the storage-battery locomotive is replacing it even in these mines. The gasoline locomotive has only one advantage over the storage-battery locomotive—its lower initial cost. Its disadvantages are the fire hazard and the poisonous nature of the fumes from the exhaust. These conditions practically prohibit its use in most Western metal mines. Except under special conditions its use should be confined to surface transportation, or to a combination of surface and underground tunnel transportation under conditions where ample natural air currents exist.

The CAR that RUNS on Air
Popular Mechanics, Feb. 1945, p. 29-31
Compressed air and vapor supply power for the "Perrymobile" that travels 60 miles on a gallon of butane

POSTWAR motorists may climb into their automobiles, step on the air instead of the gas, and glide away swiftly and silently at 60 miles to the gallon with never a gear to shift or clutch to shove.

That's the prospect presented by Frank R. Perry, Los Angeles inventor, who has built a revolutionary car called a "Perrymobile."

Untried commercially, it's a novel combination of steamer and compressed air powered automobile. The motive power comes from a secret liquid, which vaporizes at a much lower temperature than water, and compressed air which serves as an ever-ready starting and reserve source of power.

Perry says he has driven several thousand miles with his machine which is mounted on an old Ford chassis. The Perrymobile weighs only 700 pounds—about 1,300 pounds less than standard automobiles powered by the conventional internal combustion engines. The engine installation alone weighs only 140 pounds.

The 30-horsepower four-cylinder engine is turned over by pressures instead of by the explosions that move the pistons of an ordinary auto engine. The Perrymobile engine is essentially the same as a steam engine. Inside each cylinder is a piston which moves up and down and is connected to the crankshaft.

The secret non-inflammable liquid, which boils at about 150 degrees Fahrenheit, is heated by a burner which uses anything from butane gas to crude oil. The car will travel 60 miles at 30 miles an hour on one gallon of butane, the inventor claims. He says this fuel costs about 8½ cents a gallon. (He sets the top speed at "better than 70.") Only one quart of the secret liquid is required in the boiler because it is exhausted as vapor into the radiator, condensed and returned to the boiler.

The vapor passes through an intake valve into the top of the cylinder, and with a pressure of about 150 pounds per square inch pushes the piston down just as steam would do. At the bottom of the stroke the vapor exhausts through a port cut through the cylinder wall. As the piston starts up again a valve at the top of the cylinder lifts so the piston travels upward against no air pressure. At the top of the stroke more vapor is admitted which starts the piston down again.

Each of the four pistons supplies power to the rear wheels every time it is pushed down. This affords "two cycle" operation instead of the conventional "four-cycle" shift in which each piston gets a shove only every second time it travels downward. Thus, Perry's four cylinders put out as many power impulses as an eight-cylinder auto engine.

The compressed air part of the power for the Perrymobile comes from a tank under the seat. That tank is kept full of compressed air supplied by a small air pump connected by a belt with the engine. The compressed air, which flows through the boiler into the cylinders, is used for a quick start and until sufficient vapor pressure has been built up to run the engine.

To operate this revolutionary automobile, you first open the fuel valve under the hood and the burners catch fire from a pilot light. Then you get in the car and pull down the throttle lever on the right side of the steering column. Compressed air from the tank flows into the cylinders and the car starts to move.

After you have driven a few blocks the flame in the boiler has built up sufficient vapor pressure so you can turn off the air. The pump quickly restores the pressure in the air tank. Heat in the boiler is regulated by an automatic valve.

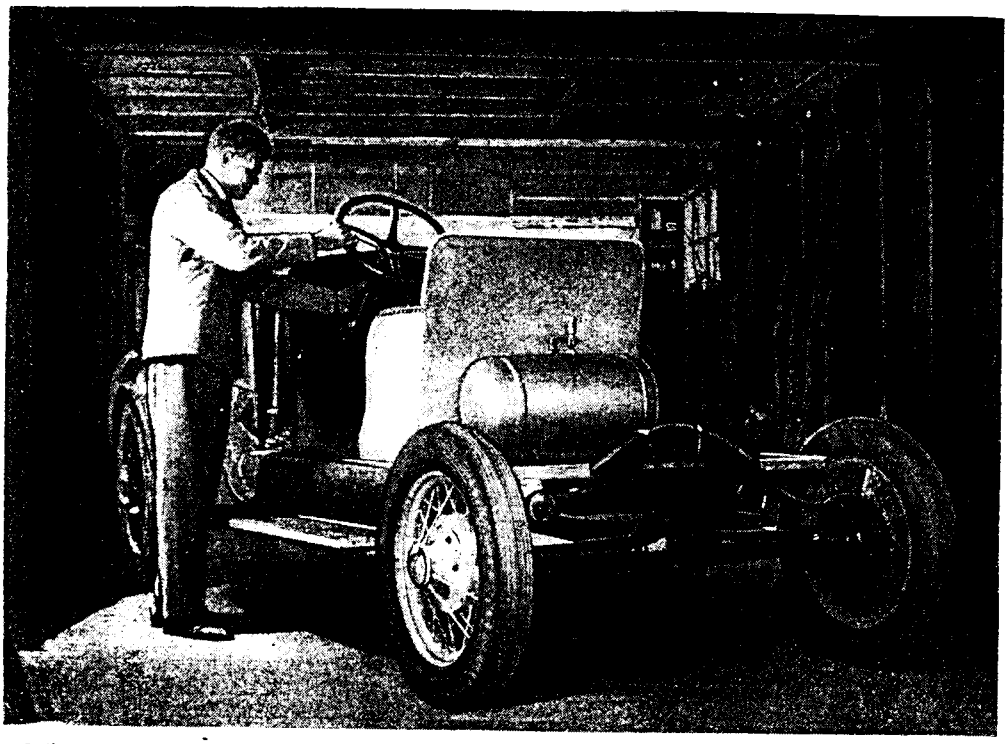
Suppose you are driving out into the country and come to a long sloping downgrade. You close the throttle, just as you would in an ordinary car, and the flame goes low in the boiler, for no pressure is being used. Even while the engine is idling, air is pumped into the tank to maintain a constant pressure. To back up, a control on the left of the steering column changes position of the cams for reversing.

The inventor compares his single control for regulating speed and power to the control lever of an electric motor. The smooth operation of the Perrymobile is due to the fact that the power output is the same at all speeds—from 1 r.p.m. to 2,000. On a gasoline engine the horsepower is in direct ratio to the r.p.m.'s.

Even at full power with the throttle valve wide open, Perry says his engine runs so cool that the paint has never blistered on the cylinders. This makes the car adaptable to extremes of climate for the liquids in it do not freeze unless the mercury drops to 30 below zero. The engine turns over slowly. At 40 miles an hour it revolves only 800 times a minute compared with 2,000 or more for most present-day cars.

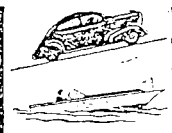
Other advantages of the Perrymobile, according to the inventor, are the "parts it does without." These include clutch, carburetor, spark plugs, distributor, coils, battery, fan, gear box and self starter. The car, of course, is equipped with brakes. Perry estimates that it will require less than one quart of lubricating oil a year. The Perrymobile makes no noise, smoke or smell. So smooth is its operation, he reports, that in a blindfold test it is impossible to tell when the car starts moving.

It cost Perry about $400 to build his lightweight automobile, but he says it should sell for much less if it gets into mass production—about $250. He believes the air-vapor engine can be used on helicopters and boats as well as automobiles.



Built on an old Ford chassis, the air-vapor car carries enough butane in its fuel tank to run 600 miles

Drive A CAR BOAT, etc. THAT RUNS ON LIQUID AIR

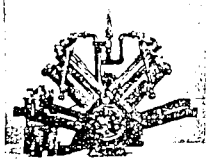


THE PERRYMOBILE

Operates with a two-unit power plant embodying only a motor and heater.

NO Spark Plugs — Clutch — Gearshift Transmission — Carburetor — Fan Distributor — Self-Starter — Fly-Wheel — No Gas, Dangerous Fumes or Noise.

LOWER COST OF OPERATION ON UNRATIONED FUEL



BUILD THE POWER PLANT YOURSELF or have it built From Easily Understood Blueprints and Specifications.

An amazing new power plant you can build yourself or have built. Operates on vapor and air pressure. Motor weighs only 65 lbs. Fits most chassis or boat. Buy or build your own parts. Hundreds of Perry Motor enthusiasts are now doing it.

FULL POWER AT ANY SPEED

Operated by vapor and air pressure. Uses kerosene, stove oil, distillate or any low grade fuel for heater. Delivers full power at any speed – from a cold start in a few seconds.

MOTOR CANNOT OVERHEAT

No fire or explosions in the Perry Motor. No carbon forms. No valves to grind. Motor cannot overheat and requires no cooling. Great saving in fuel.

THE CAR OF THE FUTURE, TODAY!

The PERRY MOTOR, pictured, is a 4-cyl. V-type motor, using crankshafts, connecting rods, pistons and valves. Will fit in chassis of virtually any make car up to 3000 lbs. gross weight.

THE POWER OF PERRYMOBILE

MAIL COUPON TODAY FOR DETAILS

PERRY-BRAUER MOTOR CO., 663 W. Jefferson Blvd., Los Angeles 7, Calif.
Please send me, without obligation, free literature further explaining the PERRY MOTOR, and cost of blue prints to build one motor for my own use.

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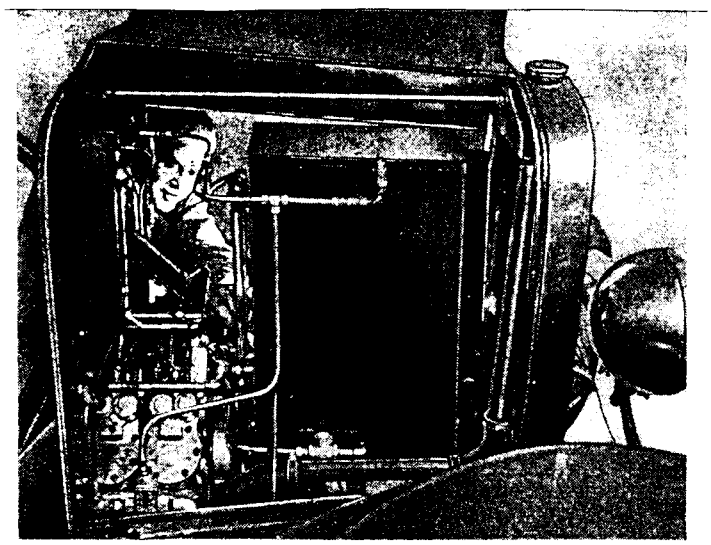
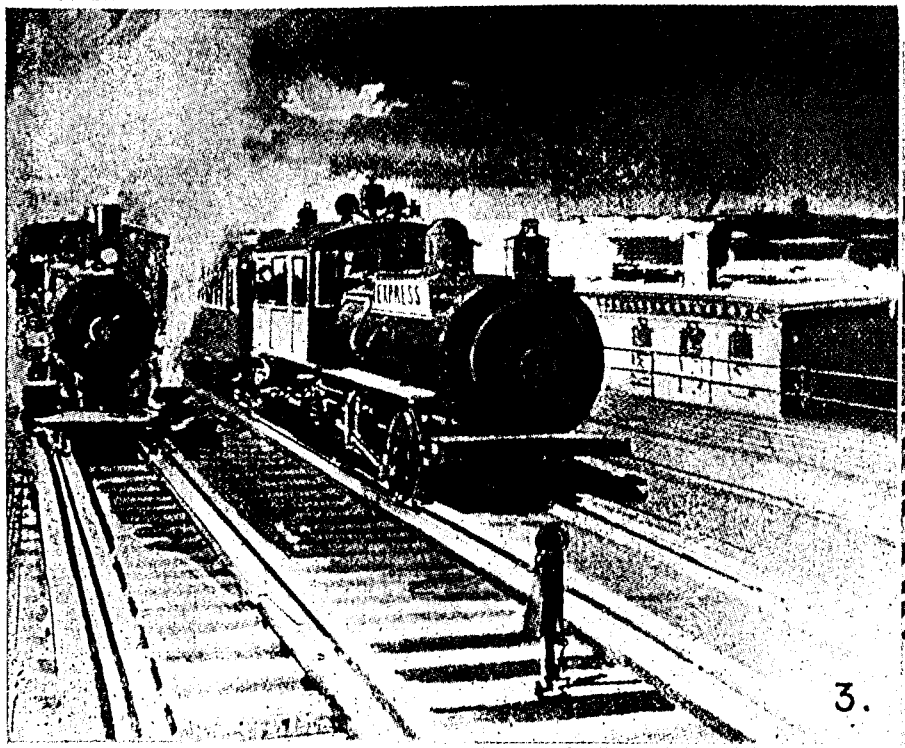
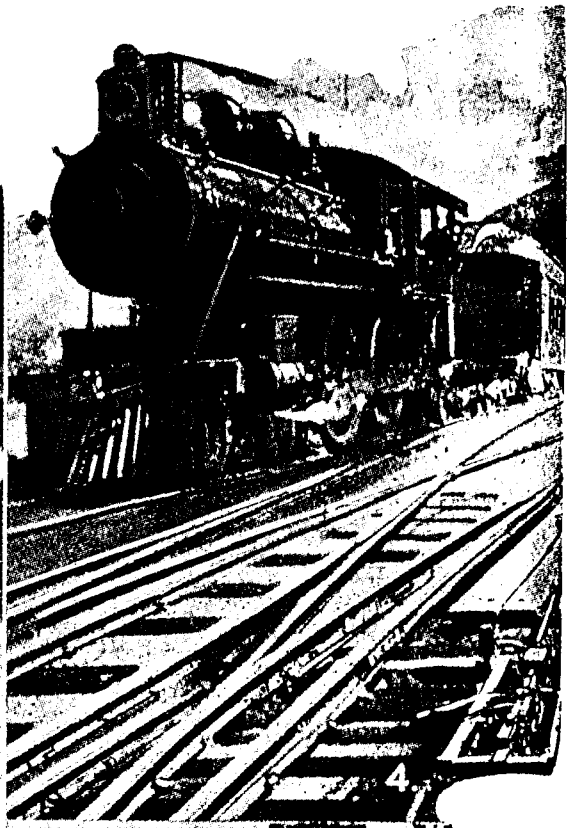


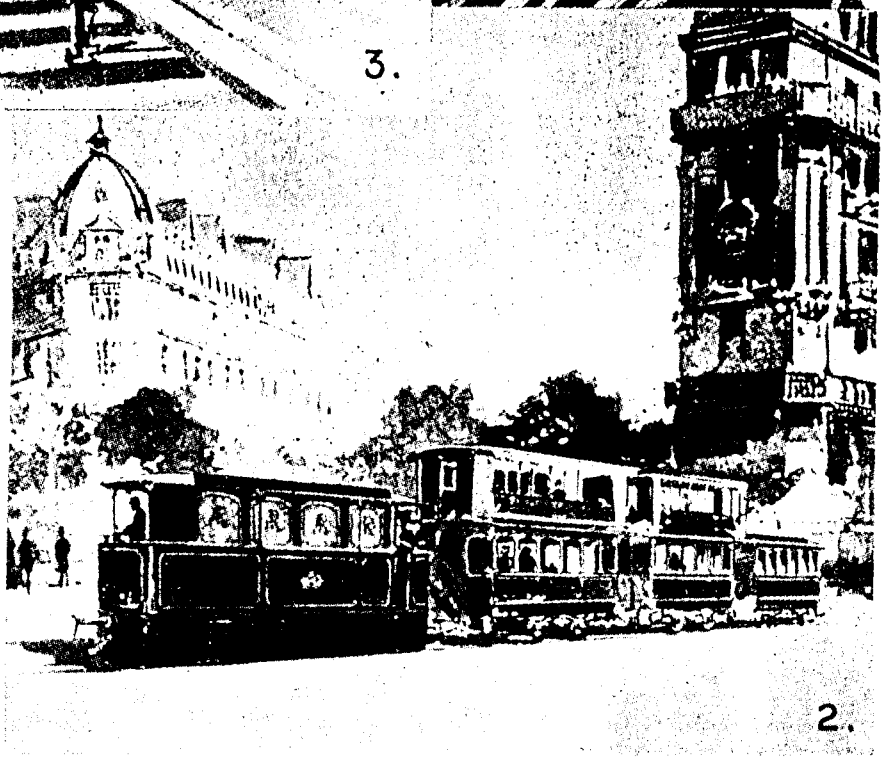
Oblong steel box houses boiler; four cylinders form a V

The only floorboard pedal is the brake; a control on steering column regulates both speed and power

Compressed Air in 1896





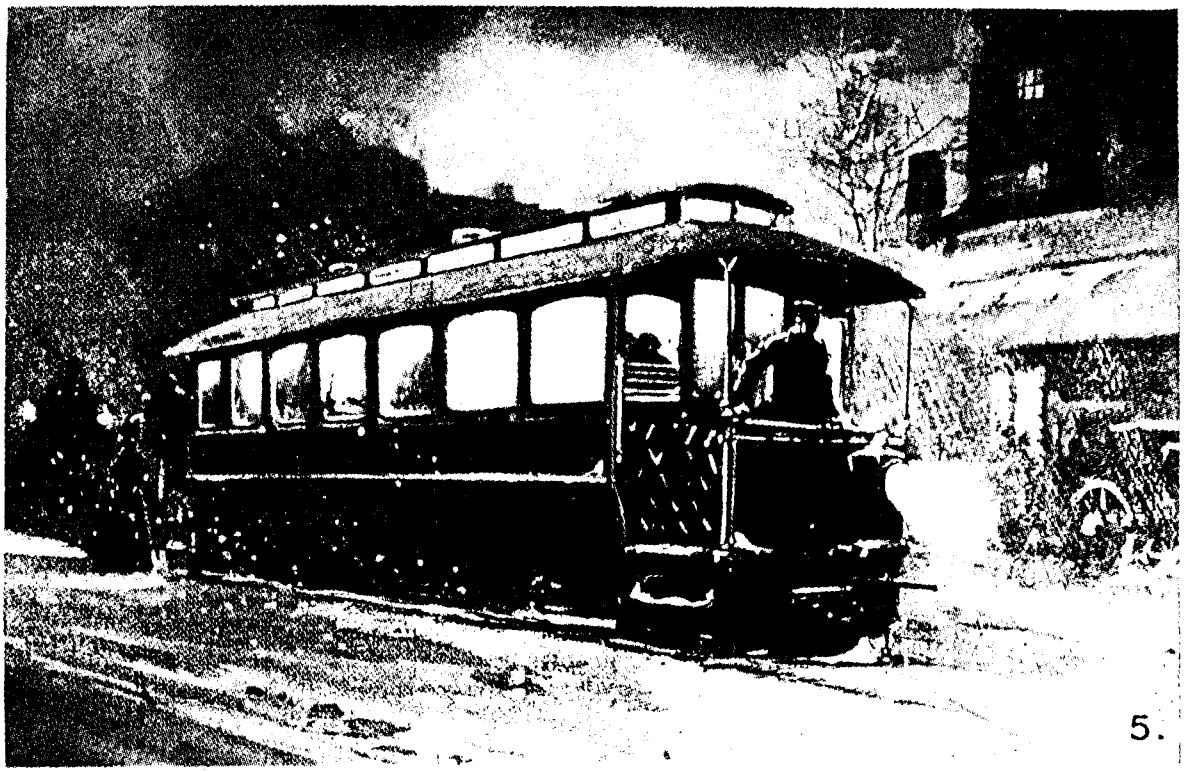


FIFTY-THREE YEARS AGO

1– Recharging storage tanks of Paris street-railway motor car with compressed air at around 2000 psi. 2– Compressed-air motor car hauling train of street cars in Paris. 3– Compressed-air locomotive (right) designed for drawing 5-car trains on the Manhattan Elevated Railroad in New York City. 4– Train in yards of Pennsylvania Railroad with switch in right foreground operated by compressed air. 5– Air-powered street car on 125th Street, New York City.

THE accompanying pictures, reproduced from the December 5, 1896, issue of *Harper's Weekly*, show some then-current uses of compressed air of which only one has survived the changing trends of more than half a century. The illustrations, all free-hand drawings by W. Louis Sonntag, Jr., covered a page in the publication, which was at the time perhaps the nation's widest-read weekly. Another full page was devoted to descriptions of the manifold applications of compressed air, which was hailed as "a very wonderful new power which has been rapidly coming into use in the last ten or fifteen years." Some of the information was credited to our own journal, then a fledgling literary project promoted by William Lawrence Saunders, who wrote in his first editorial that "the era of compressed air is now upon us . . . and the science has suffered from want of publicity."

Although the possibilities of air power had been dramatized by its employment in the Hoosac Tunnel in 1866 for operating rock drills and, subsequently, by



5.

numerous diversified applications, the 1896 American public was little informed as to the practical benefits inherent in pneumatics. Europeans were much more aware of the potentialities of this "new" science, for in Paris compressed air was being piped around to shops and even residences, and in England 150 miles of pneumatic mail tubes were already in use.

In the United States, too, compressed air was serving mankind well in many ways, but it had seemingly been "hiding its light under a bushel." *Harper's* remarked that "it has been, apparently, the Cinderella of the mechanical arts," and attributed this to the fact that "it made its appearance in an age given over to a sort of electrical mania, and there seemed no godmother genius like Tesla or Edison to bring the golden slipper to its neglected hearth."

At the moment, however, compressed air was emerging from obscurity into the sunlight of highly optimistic predictions as to its future. For three months prior to *Harper's* publicity splurge it had been operating two surface cars on 125th Street in New York with a smoothness and quietness that made them stand out in sharp contrast to the regular cable-propelled cars. The former had run 12,000 miles and carried 75,000 passengers "without accident and without incident," which caused *Harper's* writer to venture that "it is an allowable surmise that this is the traction force of the future in large cities, if not in small."

The favorable results achieved with air-powered surface cars led the same company to design and build a compressed-air locomotive to draw a train of five cars on the Manhattan Elevated Railroad between Rector and Fifty-eighth streets. The idea of pneumatic traction did not originate in the United States; it was adopted from France where the Mekarski system was the first to be successfully applied to surface lines. The development that made it operative was Mannesmann's discovery of a way to shape mild steel into seamless flasks capable of storing motive air under high pressure. From those cylinders, carried under the cars and recharged at intervals, the air was fed at reduced pressure to modified steam engines that transmitted their power to the driving wheels through gears. Various American inventors tried to improve upon the French technique, and the Hardie system was the one most used in this country. The air was stored at 2000 psi. pressure, and enough could be charged into a 51-cubic-foot cylinder to propel a car from 15 to 18 miles, including stops. On its way to the engines, the air was passed through a chest of hot water to increase its expansive effect and then through reducing valves to lower the pressure to 130 psi. at the point of application.

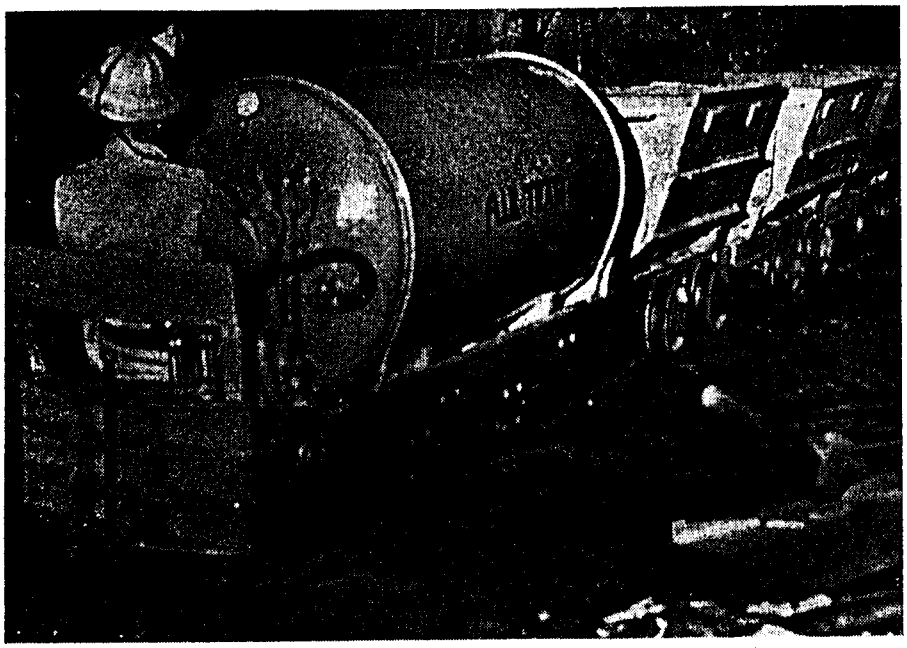
How far *Harper's Weekly* went in visualizing busy days ahead for compressed air is indicated by the following excerpt from its article: "The general use of the new power will come only with the advent of large central distributing stations, from which it can be had as freely as is gas or water now. While in a sense it is a rival of electricity, yet it is not impossible that it will soon become a yokemate rather. The alternating electrical current may be employed to transmit cheap power long distances, as from Niagara and the Pennsylvania culm-banks, and this power converted into compressed air at the points of consumption—electricity being probably the best agent for distance transmission, and compressed air the most mobile form of power for immediate use. Even this is mere conjecture, however, since there is at least one engineering genius (George Westinghouse) who has distinctly in view the compression of air at great water-powers like Niagara, conveyance by pipe lines at enormous pressure as far as New York or Philadelphia, and delivery at prices with which electricity cannot compete. But whether as yokemates or rivals, it must be clear to the dullest imagination . . . that we are but on a threshold of the day when these two forces, harnessed and trained, will, from their cheapness and availability, and in their infinite application, lift a considerable share of the burden of physical toil from the shoulders of the race."

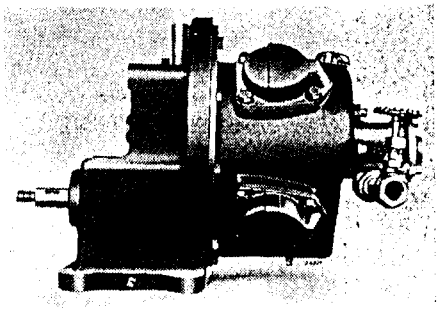
The prophecy in the last sentence has been fulfilled, probably even beyond the most optimistic dreams of the 1896 writer. Meanwhile, electricity and compressed air have gone their separate ways, each serving certain fields for which it is best adapted, but also joining forces in numerous directions. Both are still advancing by leaps and bounds, for there seems to be no end to their usefulness.

As for the compressed-air applications illustrated, pneumatic street-car propulsion died aborning, although the same method was vigorously exploited for underground transportation in mines, where it still finds limited use. But the operation of switches by air power under electric control continues to be accepted practice.

Compressed Air Magazine
December 1952
p. 351

Air Mules





IMPROVED AIR LOCOMOTIVE

The low-pressure Air Tram pictured here is making a test run with three mine cars but is built to haul from four to eight, each with a capacity of about 20 cubic feet, on grades from ½ to 2 percent, depending upon the condition of the track, the number and radii of the curves, etc. It is driven through easily removable chains and sprockets by an EE3G air motor such as shown. The bumper is of new design for greater locomotive protection and more leeway in coupling. The operator's seat is provided with a foam-rubber cushion for comfort.

WHERE mine or tunnel track haulage is less than half a mile long, where grades do not exceed 2½ percent, and where air at 100 psi pressure is available, pneumatic locomotives are often applied to advantage. The Mechanics Service Company of Cripple Creek, Colo., builder of the original low-pressure Air Tram, has recently put on the market a greatly improved model which marks a big step forward in this field of transportation.

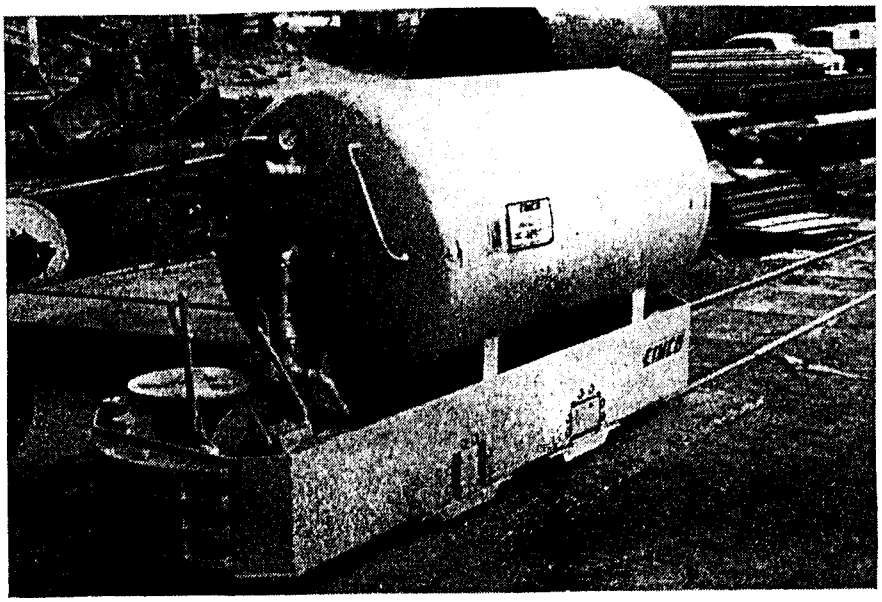
The first compressed-air locomotive, built in 1873, was inspired by the desire to provide a tractor for coal-mine haulage that would be safer, more reliable and economical, and less complicated than the electric systems that were then replacing hand and mule tramming in large mines. Air motors were comparatively crude and inefficient at that time. To develop enough power to pull a string of cars, the "air hogs," as they were often termed, required exceedingly high pressures that called for large multistage compressors, heavy-duty air lines, and bulky air tanks on cumbersome machines that had a limited field of application. Hence the air-driven locomotive was slow in developing, but experimenters kept the idea very much alive.

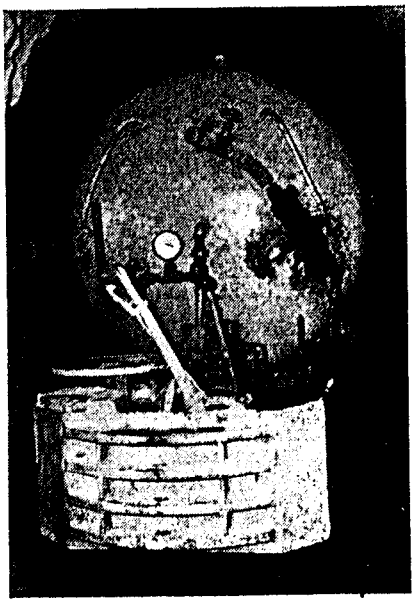
In 1904 the colliery of the International Coal & Coke Company, Ltd, of Coleman, Alta., was equipped with a compressor and three air locomotives by Canadian Rand Drill Company, Ltd (now the Canadian Ingersoll-Rand Company, Ltd), and thus became Canada's first air-haulage mine. Air at 1000-1200 psi pressure was needed to run those early tractors, and receivers were usually tested at 1800 psi. Some high-pressure units are still in service, but most installations are of the low-pressure type. Efficient air motors and mechanical improvements in pneumatic trammers now permit the use of a comparatively small tank with a capacity of 49 cubic feet. This is charged with air at 100 psi, and even though the pressure may drop to as little as 5 psi in service it is still sufficient, it is claimed, to drive the newest locomotive.

The Air Tram is operated by a 5½-hp Ingersoll-Rand air motor, and power is transmitted from motor to axle and from axle to axle by 1-inch pitch roller chains engaging hardened-steel sprockets. During recent tests in the Chicago Tunnel of the Globe Hill Mining Company in the Cripple Creek District, a tractor traveled 3300 feet, or 55 feet per cubic foot of air consumed, without refilling its 36x84-inch receiver. During another test, run over the same track on a maximum grade of 2½ percent, the unit pulled three mine cars a distance of 2100 feet on one air charge, or about 40 feet per cubic foot of air used.

The air motor that helps to make this economical short-haul transportation possible is built for heavy-duty continuous service. It is of the variable-speed, radial type that can be instantaneously reversed and cannot be damaged by overload. Its enclosed construction is a desirable feature for underground work because it excludes dust and dirt and permits complete and automatic lubrication of all moving parts. Other advantages are renewable and interchangeable cylinders to and from which air is admitted and exhausted by one rotary valve. To sum it up, this piston-type motor is especially well adapted for service where plenty of lugging power is needed.

Equipment Shown Below . . .





TWO-SPEED COMPRESSED AIR LOCOMOTIVE weighing 3,260 lb. with 58-cu. ft. receiver arrived from Eimco factory (left). Gear speed ratios were modified and the unit was installed for drift haulage as shown at right.

Engineering and Mining Journal—Vol.154,No.8 August 1953, p. 72-74

Granby Adopts Air Trammers— Cuts Drifting Labor Costs 26%

D. W. PRINGLE
Assistant Mine Superintendent,
Granby Consolidated Mining,
Smelting and Power Co., Ltd.,
Copper Mountain, B. C.

SUBSTITUTION OF A two-speed air locomotive and 3-ton automatic dump car for hand tramming methods at the Copper Mountain mine of Granby Consolidated, British Columbia, resulted in labor savings of 26%. In one drift heading with a tramming distance of over 900 ft. the contract price for labor was reduced from $13.05 to $7.50 per ft., a reduction of 42.5%. The drifting crew in this long heading was reduced from five men to two men, while bonus earnings per man increased almost 41%.

For the past several years, numerous articles have appeared concerning the use of small compressed air locomotives for underground tramming, particularly as an aid for advancing drift headings. This led to the building of such a machine in the Copper Mountain shops in 1950, which, however, was unsuccessful. In the summer of 1951 the writer investigated the use of this type of machine in the Coeur d'Alene district in Idaho and was convinced that with suitably designed equipment, major reductions in the cost of drifting could be achieved.

The standard drifting crew consisted of two miners, one mucking machine operator, and one helper and required two 8-hr. shifts for an average advance of 7.12 ft. as shown in Table 4. The round was drilled by two miners using 44-lb. jackhammers mounted on air legs and integral steel tipped with a tungsten carbide chisel or four-wing bit. An average round consisted of from twenty to twenty-six 7½-ft. holes. Permanent track and pipe installations were made on the drilling shift by company men or by the contract crew which was allowed company time for such work.

On the mucking shift, the mucking machine operator and helper first wet down the muck pile and barred down loose rock. Then, using a high deck mucking machine and a 1¼-ton end-dump car, they loaded from 15 to 21 cars which were hand trammed to a dump. When the tramming distance reached 900 ft., an extra helper was required. The contract price was then increased to yield the same bonus as the four-men crew would have earned for the same footage advance. As shown in Table 4 this necessitated an increase from $10.64 to $13.05 for labor only.

Drifting bonus is computed by multiplying the price per foot times the footage advanced in each two-week period. From this figure the total wages are subtracted and the balance is divided evenly among the crew in proportion to the man-shifts worked. Miners' wages per 8-hr. shift are $12.66; mucking machine operators, $12.24; and helpers, $11.44. The basic price for drifts up to 8x8 ft. in size using the equipment outlined above is $10.14 per ft. with $0.50 per ft., increase for every 500 ft. of tram. Table 3 shows the earnings possible at this price for different footage advances. Under the heading "Old Contract Price" in Table 4, the average bonus for 628 ft. of advance was $6.25 per man-shift for an average advance per round of 7.12 ft.

Today's Drifting Methods

The writer had observed the one-speed air locomotive and auto-dump cars in operation in the Coeur d'Alene mining district. From these time studies it was concluded that a two-man crew could complete a cycle (i.e. muck out a round, drill

TABLE 1—Estimated Drifting Cycle

	Hr.	Min.
1. Traveling to face, barring & wetting muck pile	0	30
2. Loading, tramming, dumping 9 cars @ 12 min. each (1,000 ft. of tram)	1	48
3. Lunch	0	30
4. Drilling twelve 5-ft. holes @ 6 in. per min. (per machine)	2	00
5. Removing drill gear and blowing holes	0	20
6. Loading and blasting round	0	20
7. Traveling time to surface	0	30
Total time required to complete cycle	5	58
Balance of 8-hr. shift for track work, pipe work, etc.	2	02

TABLE 2—Summary of Advances and Bonus Earned During Trial Period

Date	Man Shifts	Rounds	Footage Average	Footage Total	Bonus Average	Bonus Total	Tramming Distance, ft.
May 1–15	46	24	4.75	114	$8.40	$386.64	710– 824
May 16–31	50	25	5.08	127	8.93	446.82	824– 951
June 1–13	34	17	5.00	85	8.59	292.06	951–1,036
Total and Averages	130	66	4.94	326	$8.65	$1,125.52	873

TABLE 3—Possible Bonus Earnings per Man Shift at Various Prices

Length of Advance, ft.	New prices and a 2-man crew $8.50/ft.	$7.50/ft.	$7.00/ft.	Old price and a 4-man crew $10.14/ft.
5	$ 8.59	$ 6.09	$ 4.84	$0.42
6	12.84	9.84	8.34	2.96
7	17.09	13.59	11.84	5.49
7½	19.21	15.46	13.59	6.76

TABLE 4—Comparison of Old and New Contract Prices

4-270 DRIFT—OLD CONTRACT PRICE

Period	Price	Adv. (ft.)	Miner Shifts	Adv. per round	Mucker shifts	Total shifts	Bonus per man shift	Ftg. per man shift	Tram distance, ft.
Jan. 1–15	$10.14	39	10	7.80	10	20	$7.52	1.95	356– 395
Jan. 16–31	10.14	53	15.5	6.84	16	31.5	4.84	1.68	395– 448
Feb. 1–15	10.64	16	19.5	6.97	20	39.5	5.47	1.72	448– 516
	10.14	52							
Feb. 16–29	10.64	50	14	7.14	14	28	6.75	1.78	516– 566**
Mar. 1–15	10.64	64	20	6.40	19.5	39.5	4.98	1.62	586– 650
Mar. 16–31	10.64	73	20	7.30	20	40	7.14	1.82	650– 723
Apr. 1–15	10.64	41	10.75	7.63	11.5	22.25	7.16	1.84	723– 764
Apr. 16–30	10.64	58	16	7.25	16	32	7.01	1.81	764– 822
May 16–31	10.64	16	8	7.00	10	18	5.99	1.55	822– 850
	*13.05	12							
June 1–13	*13.05	50	13.5	7.41	21½	35	6.55	1.43	850– 900
Totals & averages		524	147.25	7.12	158.5	305.75	$6.25	1.71	628

NEW CONTRACT PRICE

Sept. 16–26	7.50	55	32	5.25	31	63	$8.24	2.67	945–1,113
	8.00	113							
Oct. 1–15	8.00	99	16.5	6.00	17.5	34	10.63	2.91	1,113–1,212
Oct. 16–31	8.00	152	37.5	4.05	28	65.5	5.90	2.32	1,212–1,364
Oct. 30–Nov. 13	8.00	157	28.5	5.51	28.5	57	9.46	2.75	1,364–1,521
Nov. 14–29	***8.43	164	29	5.66	29	58	11.53	2.86	1,521–1,685
Nov. 30–Dec. 13	8.43	177	34.5	5.13	34	68.5	8.61	2.58	1,685–1,862
Dec. 14–28	8.43	42	8	5.25	9	17	7.65	2.47	1,862–1,904
Totals & averages		959	186.0	5.16	177.0	363.0	$8.80	2.64	1,424

Notes: *Price adjusted for extra helper on mucking cycle. **20 ft. advance done during test work. ***Wage increase.

off, and blast) with 8-ft. steel on a short tram, and with 6-ft. steel on a long tram. As a result, an air locomotive was purchased and a special dump car built in our shops.

The Air Locomotive

The air locomotive is a 3,260-lb. unit, equipped with a 58-cu. ft. receiver and air motor as shown. The 7½-hp. air motor is coupled by an oil-bath friction clutch to a two-speed gear box. The gear box has a reduction ratio of 1.5:1 in high and 3.5:1 in low, and from the drive sprocket to the axle the reduction ratio is 2.5:1. Both axles are joined by a drive chain producing a four-wheel drive which gives ample traction for pulling heavy loads. Low gear is used for starting with a heavy load or when the air pressure in the tank is low. High gear is used after the locomotive is moving, for good track conditions, and with good air pressure. Neutral is used for coasting on good track. Since low gear was seldom used at Copper Mountain because of the straight track, the rear end ratio was changed to 2:1 which had the effect of increasing both the range of travel and the speed in both gears.

This change was made to the locomotive when it was operating on a 1,400-ft. tram. Some crews were charging the receiver going out. After this change was effected, the trip out was made with one tank of air. This drift broke through 1,904 ft. from the dump. When the air pressure was above 85 lb. the tank was charged four times for the round trip; at the face on the out trip, at the dump, at 600 ft. and at 1,200 ft. on the return trip. Average speed over the round trip distance was 5.5 mph.

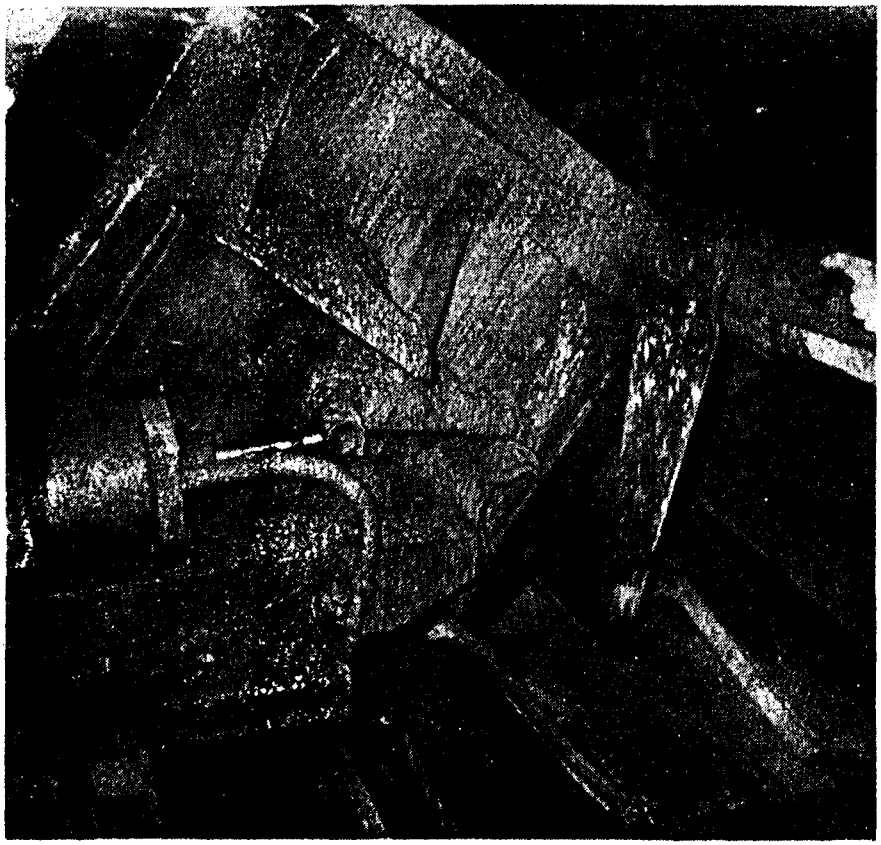
Charging the air locomotive is accomplished by using an automatic shut-off quick-change valve. Charging stations are spaced about 600 ft. apart. Usual charging time is about 40 to 60 sec., depending on the tank pressure.

The auto dump car is a 50-cu. ft., 3-ton, side-dump car as shown. Two 8-in. air cylinders, one on each end of the car and controlled from the locomotive by the motorman, dump the car. A minimum of air pressure of 60 psi is required to actuate the dumping mechanism.

With the use of this equipment, it was estimated that two men

TABLE 5—Actual Drift Cycle

	Hr.	Min.
1. Traveling, headframe to heading	0	23
2. Muck out round—9 cars @ 11 min. each	1	38
3. Setting up	0	07
4. Drilling 11 holes per machine @ 7½ min. each	1	24
5. Lunch	0	35
6. Tear down, blow holes, load, spit	0	43
7. Miscellaneous	0	18
8. Heading to 5L station	0	23
Total time required to complete cycle	5	31
Balance of 8-hr. shift for pipe work, track work, surveyors, etc.	2	29



AUTO-DUMP CAR contains two 8-in. air cylinders mounted on either end of car. Compressed air from the locomotive receiver dumps the mine cars.

would be able to complete the cycle shown in Table 1.

In the case of a short tram it would be possible to drill 8-ft. steel and average 7.5 ft. advance per round. At the standard price of $10.14 per ft. a $25.00 bonus per man would be possible.

Union Negotiations

In accordance with our union agreement, contract prices cannot be changed until agreement has been reached with the Union Contract Committee. Therefore, on April 7, 1952, a letter was written to the union requesting re-negotiation of the contract price for an 8x8-ft. drift using this modern equipment.

Our first meeting was held on April 19, 1952. The union committee at first refused to consider any reduction in contract price which they contended involved speed-up and possibly paying for company equipment by reducing contract drift prices. They also intimated that they did not think the air locomotive would speed up the tramming sufficiently to permit cycling. The basis on which the company officials requested this reduction was the maxim—"equal bonus for equal effort." After a lengthy discussion a trial price of $8.50 per ft. was set for the first 300 ft. of advance.

By June 13 the trial distance had been driven. As shown in Table 2 the bonus earned was $8.65 per man-shift for an average round of 4.94 ft. where the average tramming distance was 873 ft. See Table 3.

During the trial period all crews admitted that with the aid of this modern equipment their physical effort was definitely less. On the basis of the above performance and additional time studies, the company officials then considered a fair and reasonable price would be $7.00 per ft. as shown in Table 3.

At this price for a 7-ft. advance, the bonus would be increased from $5.49 per shift to $11.84 per shift. On the other hand the company would have a direct saving of $3.14 per ft. on the basic price.

A Compromise Reached

The July 4, 1952, meeting produced a compromise price of $7.50 per ft. with a $0.50 per ft. increase from a 1,000 to 1,500-ft. tram and a $0.25 per ft. increase for each additional 500 ft. of tram. This price is still a little high but the principle has been established of reducing contract prices when new equipment or techniques can be applied. Table 4 shows the drift performance in 4-270 drift under the old contract and under the new contract.

Table 4 shows that tramming distance increased from 356 to 1,904 ft. The average bonus earnings increased from $6.25 per shift to $8.80 per shift. It also shows that the advance per man shift increased from a low of 1.43 ft. to a high of 2.91 ft. or an average increase from 1.71 ft. to 2.64 ft.

A time study of a typical round after the men had become accustomed to the equipment appears in Table 5.

This time study of an actual cycle is very close to our theoretical cycle proposed to the union committee. It also shows that the price is still high.

Air vs. Storage Batteries

The question naturally arises as to the relative merits of this type of compressed air locomotive compared with the conventional 1½-ton storage battery locomotive which is often used for this type of work. In our opinion each has its place. The compressed air locomotive costs less than half as much as the storage battery locomotive. It can be operated with relatively unskilled labor since supervising and charging of batteries does not have to be considered. Using the air from the locomotive air tank to dump the car is a great advantage. On the other hand the battery locomotive would appear to be the answer for longer hauls, particularly if it is desired to switch cars at the face, make up a train of several cars, and haul to a dump several thousand feet away, for example.

The air locomotive and the auto-dump car have been very effective for drifting, producing the following results: less physical effort on the part of the workman with an increase of bonus earnings, a decrease in drifting costs for the company and a decrease in the total number of men employed.

Much of the credit due to the success of this achievement belongs to the workmen involved and to the officials of the local union for their cooperation.

The writer wishes to thank the Granby company for permission to publish this paper. Special thanks are due J. A. C. Ross, mine superintendent and P. E. Olson, test engineer, for their valuable assistance in the preparation of this article.

INTRODUCTION TO MINING

BY

BOHUSLAV STOČES, D.Sc., 1954

Member of the Institution of Mining and Metallurgy, London; Membre perpétuel de la Société géologique de France; Membre à vie de la Société géologique de Belgique; Member of the Society of Economic Geologists, Washington

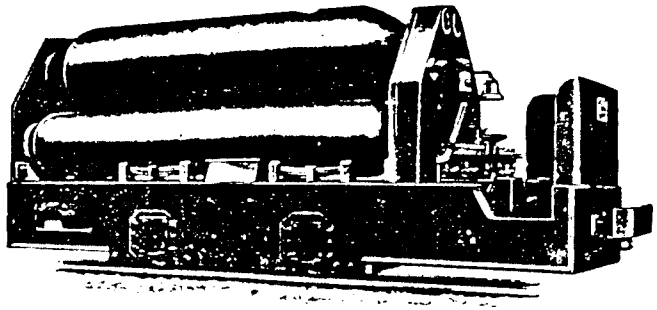


Fig. 382. Mine locomotive driven by compressed air, carried in storage cylinders. Jung type.

Proper measures should be taken to prevent any leakage at the carburettor and caution should be used when the tanks are charged.

Compressed-air locomotives have not this disadvantage, but they have to carry along a supply of compressed air in cylinders, at a pressure of about 175 atmospheres. After a certain number of trips the cylinders have to be refilled. To provide the compressed air, a special high-pressure compressor is needed on the surface, and from it a high-pressure pipeline leads through the shaft to the filling stations. From the cylinder the compressed air goes through a reduction valve to reduce the pressure to about 15 atmospheres to the first working cylinder. As, however, air cools by expanding, and as it has still to work in the second cylinder, we have to provide for its heating. This is done by passing it through a heater heated by a current of warm mine air.

Compressed-air locomotives are the safest kind of locomotives, as there is no fire or sparking and they do not exhaust any noxious gases. They aid ventilation. Being sufficiently flexible in operation, they are the best kind of engines for gassy or poorly ventilated mines or magazines of inflammable material. The following installations are required: A multi-stage compressor with a pressure of about 200 lbs more than is needed by the engine, furnishing air at the average rate of consumption; stationary storage tanks, or a long transmission line acting as storage, near the charging station; a number of charging stations according to the required radius of the locomotive; and a locomotive of proper efficiency and capacity. The pressure required is so high that an ordinary mine compressor cannot be used for this purpose. The multi-stage compressor might, however, take its supply from a receiver of the mine compressor, instead of from the atmosphere.

DRAGGING

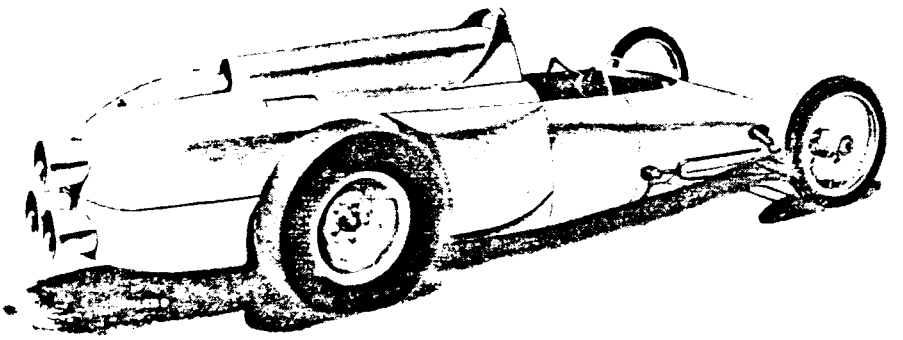
DRAG FANS around the country will soon be treated to something different in dragsters when the Speed-Sport Shop Special fires (?) up for a nationwide tour. Long famous for their 170-plus-mph modified roadster, the Tucson, Arizona speed merchants have forsaken their fuel-burning monster to come out with the world's first air turbine-powered car.

Driven by three modified jet aircraft starter motors, manufactured by AiResearch's Phoenix division, the dragster used compressed air as fuel.

The starters were originally designed to boost jet engines, such as those used in the Boeing 707, to starting speed. The compact units each weigh 35 pounds, and in a slightly modified form each puts out 200 air horsepower.

Air for the units is contained in lightweight aircraft air bottles mounted behind the driver. A 15-second supply of air at 3000 pounds per square inch powers the ¾-ton rail.

This air, heated by combusters, spins the turbine wheels in each of the starters at 70,000 rpm. Reduced through gearing, this reaches the differential at 8000 rpm. Early tests have produced speeds in the 160-mph, nine-second e.t. range. /MT



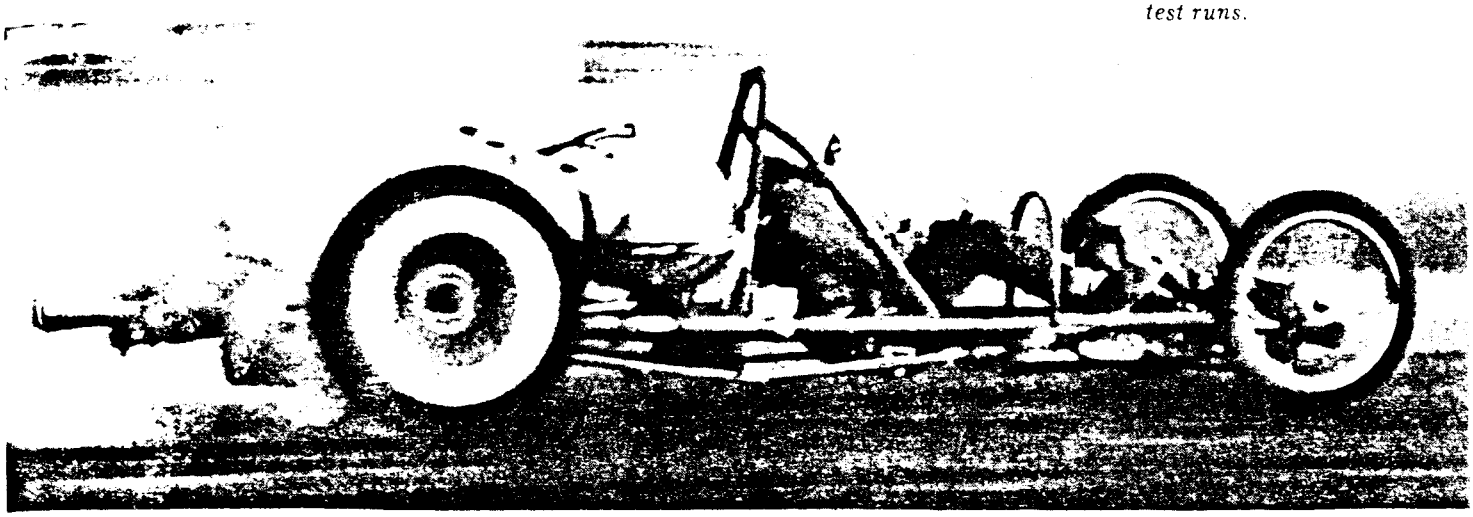
Artist's conception shows the sleek aluminum body that is currently being built for the dragster.

Jet aircraft starter motors using compressed air as fuel provide the unique power for this experimental dragster that has covered the quarter-mile in the nine-second range

ON AIR!

THE AIR DRAGSTER'S CREW CHECKS OUT THE COMPRESSED AIR TANKS BEFORE ONE OF THE TRIAL RUNS HELD RECENTLY IN PHOENIX, ARIZ.

Screaming like a banshee, the revolutionary Speed-Sport car lights up the tires on one of its nine-second quarter-mile test runs.



Automotive Engineering 83 (Jan. 1975): 25.

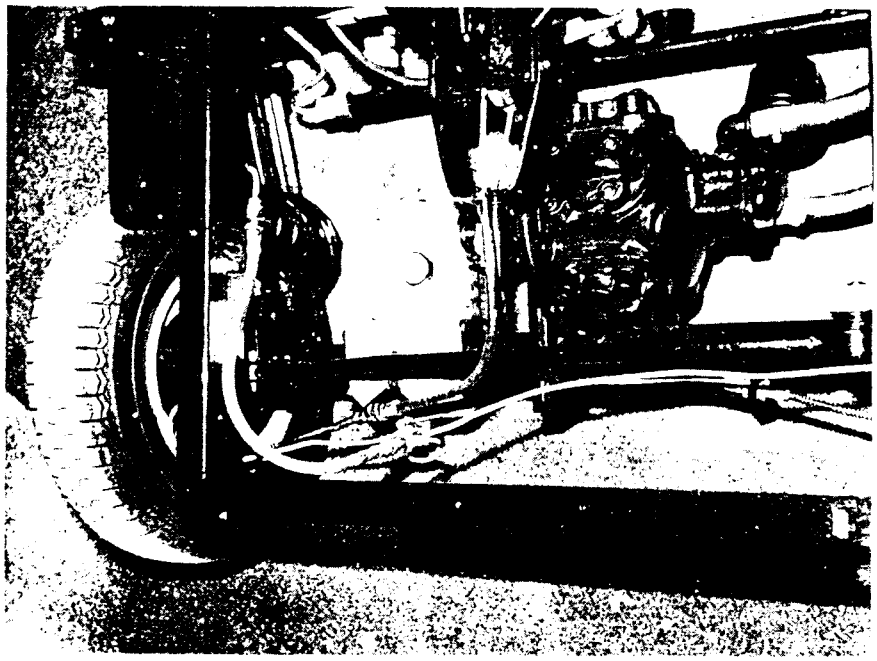
Air Car Rivals Electric

Compressed air drive is proposed by Sorgato in Italy as a viable fuel-economy alternative to the electric car for industrial and urban use. Originally conceived for operation in hazardous areas such as mines and chemical plants where ignition or other electrical discharges could spark off an explosion, the basic concept consists merely of a bank of storage cylinders feeding an air motor through pressure-reduction and throttle valves.

The first experimental model, built to demonstrate the idea, has nine air bottles charged to 2840 psi by an external compressor. This pressure is reduced to 85 psi for the five-cyl radial motor, which drives the rear wheels through a simple reduction gearbox with integral differential.

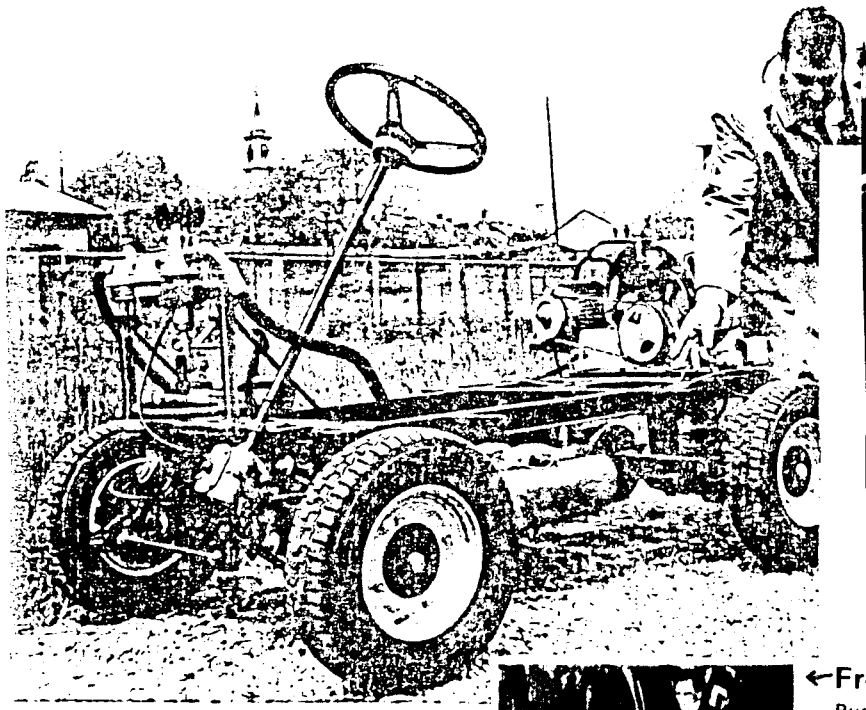
Top speed of this near-silent and non-polluting vehicle is 30 mph, and duration is said to be about two hours. A forward/reverse valve controls direction of travel. The chassis illustrated weighs 770 lb.

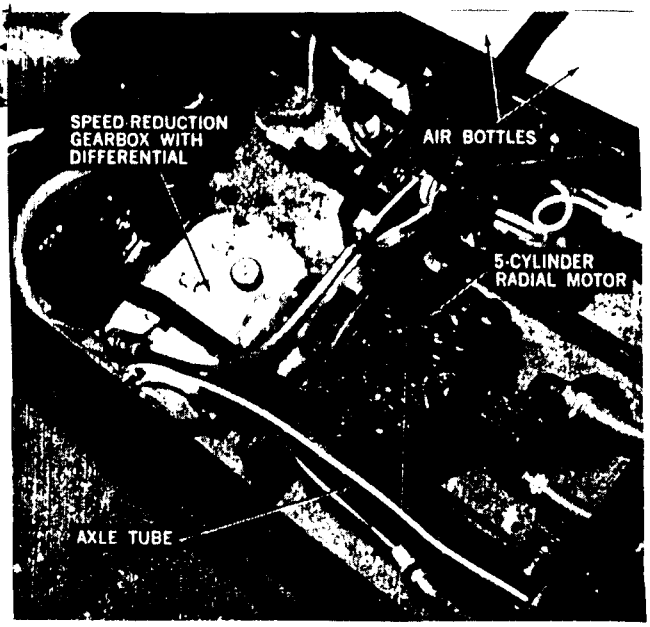
Advantages claimed for pneumatic drive over conventional storage batteries are rapid recharging (time dependent solely on the supply pressure available), simple speed-regulation, low cost construction and light weight. Further development of the air storage system and motor is underway, and the company plans to market small delivery vans based on a refined version of the present chassis design.



HERE IS VITTORIO SORGATO'S AMAZING LITTLE COMPRESSED AIR AUTO NEAR MILAN ITALY (73)

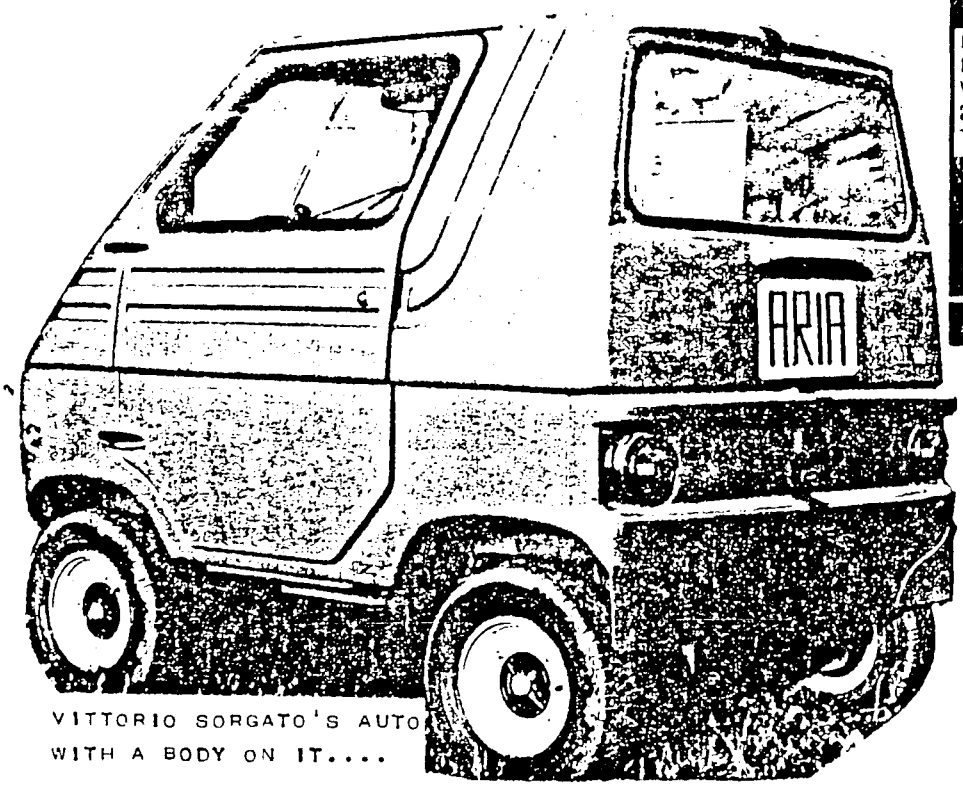
Popular Science March 1975



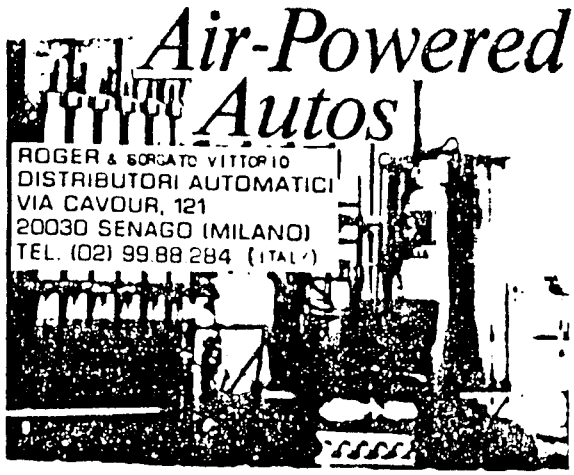


←From Italy: pollution-free pneumatic drive ↑

Push the throttle of Soragato's experimental compressed-air car and all you'll hear is a hushed puff-puff-puffing. The car, shown at an Italian exhibition, runs on air from nine cylinders slung under the frame. A five-cylinder, three-hp radial motor (above) works with a simple reduction gearbox and rear-wheel differential drive. Top speed is 30 mph, and duration is about two hours—a 60-mile range. There are no gears to shift and the exhaust is plain air. Recharging the bottles to 2840 psi takes only an hour or two.



VITTORIO SORGATO'S AUTO WITH A BODY ON IT....



Compressed-Air Hybrid

Some of your readers, who studied the interesting article on Electric Vehicles in the August edition, may like to spare a passing thought on the merits of pneumatic vehicle propulsion. Almost all the arguments and relationships presented in the paper still hold good if compressed air is substituted for electricity. But the real interest lies in the differences.

It is not likely that a reasonable range can be achieved on stored compressed air alone, so that a hybrid, with an engine covering mean power demand to drive the air compressor, needs to be considered.

The potential transmission efficiency of a pneumatic transmission is high compared to the electric analogue and if heat from the charging engine exhaust is used to heat the driving air, a transmission efficiency in excess of unity is possible. In fact, with an open circuit layout, such an arrangement is necessary to avoid freezing in the air motor exhaust.

There is no limit to the charge or discharge rates and no difficulty in applying 100% regenerative braking. What is more, it is a lot simpler to store air at, say, 100 psi than to store electric energy in a high speed flywheel. There is also no battery charging loss and no battery weight; the storage weight of compressed air is small and it all but disappears if chassis members are made to double as air receivers. The weight of air motors is infinitesimal compared to electric drive motors and nothing cleverer than a few valves is needed for propulsion control. There would be two or more air motors, so there is no need for a differential either.

The charging engine, which either stops or runs at constant speed and load, can be tuned to maximum efficiency and minimum exhaust emission and if the economy steps found necessary for the electric vehicles are applied to the pneumatic hybrid, it should be possible to attain quite phenomenal fuel mileages.

Finally, the traditional skills of the automotive industry could readily encompass the development and production of such a vehicle.

Dr. S. G. Bauer
Derby, England

Lawrence Livermore Report UCRL 52553, vol. 2, pages 1/16-17. 1978

1.2.2 Compressed Air Systems

Compressed-air energy storage systems are defined as those that compress air at ambient conditions, store it in a receiver, and extract energy by allowing the air to expand through a motor back to atmospheric pressure. Suggestions for using such a system to augment the power capabilities of vehicles do surface occasionally.[2] The only known vehicle utilizing compressed air is a prototype of golf cart size built in Italy.[3,4] Its sole source of power is the compressed air which is stored at 20.7 MPa (200 atm) in nine steel cylinders. The test pressure of these cylinders is 31 MPa (300 atm) and their theoretical burst pressure is 83 MPa (800 atm), indicating a safety factor of 4:1 based on ultimate strength. It is powered with a 5-cylinder radial air motor rated at about 3.75 kW (5 hp) with working pressure of 0.62 MPa (90 psi). This vehicle is only 2 m long and weighs about 500 kg (1100 lb). Its application is limited to industrial complexes where its range and speed requirements are equivalent to those of a pick-up truck or small delivery cart. Under these circumstances, it is claimed that the vehicle will operate for about 4 h between charges, which can be accomplished in a matter of minutes. While it is also claimed that this vehicle can reach a top speed of 40 km/h (25 mph), its range at this speed would be too insignificant to qualify it as a passenger vehicle suitable for public roads.

U.S. Patent Gazette FEBRUARY 1, 1983 GENERAL AND MECHANICAL

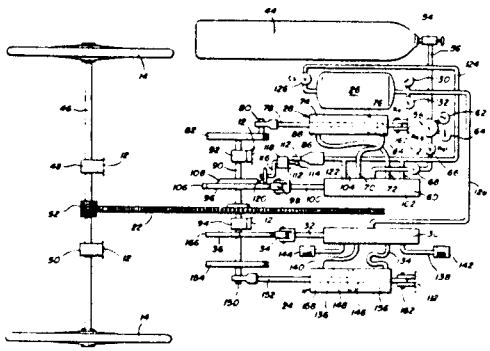
4,370,857

PNEUMATIC SYSTEM FOR COMPRESSED AIR DRIVEN VEHICLE

Terry R. Miller, Box 80, Crestline, Kans. 66728

Filed Jul. 11, 1980, Ser. No. 167,524
Int. Cl.³ F60D *31/02*
U.S. Cl. 60—413 5 Claims

4. In a fluid power operated motor system, including at least one pair of double-acting piston devices respectively having piston elements and a storage source of pressurized fluid, the improvement comprising, pressure accumulating means operatively connected between said piston devices for transfer of fluid exhausted from one of the piston devices to the other of the piston devices, valve means connected to said piston devices for pressurization of said one of the piston devices and limiting said transfer of fluid exhausted therefrom to spaced intervals of time during which the storage source and the pressure accumulating means are substantially equalized in



pressure, and vent means for venting the fluid exhausted from said one of the piston devices between said spaced intervals of time.

Seventeen Magazine July 1980

hot lines

RUNNING ON AIR

If you accused twins John and Robert Holcomb—plus three of their classmates—of being full of hot air these days, you'd almost be right! The five Buffalo, Oklahoma, teens have banded together and built an air-powered vehicle, with the help of their Buffalo High School physics teacher.

Quiet, pollution-free, and economical, the "car" glides along without a sound, except for the whoosh of air that powers the vehicle. Dubbed Mariah by its builders (after the song *They Call the Wind Mariah*), the two-seater vehicle resembles a three-wheeled motorcycle with bucket seats.

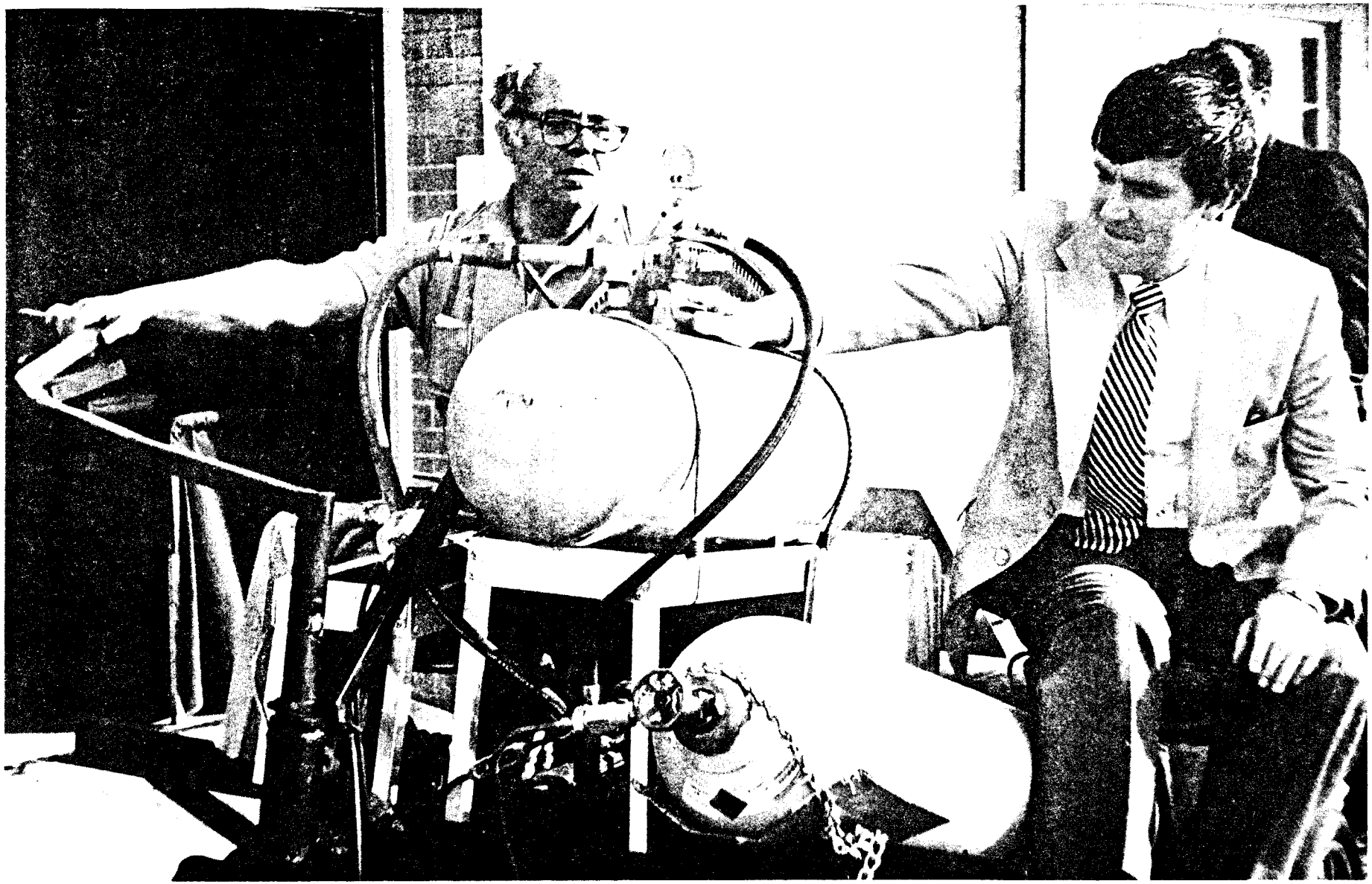
The Holcomb brothers, 18, and their fellow physics students, Paul Yauk, 18, Lonnie McManus, 17, and Ron Catlin, 16, designed and built the car in two months. They were inspired when their physics teacher, Gwen Cook, returned from a visit to an energy exposition in Dodge City, Kansas, and told her class about an air-powered car built by Terry Miller, an aircraft mechanic. Intrigued by the idea, the boys got the car plans from Mr. Miller, designed their own body, and, in their spare time, built their own air car.

The car is powered by compressed air. "It works on the same principle as steam engines, but without liquid," Ms. Cook explains. The compressed air forces pistons in the engine to move up and down, causing the motor to turn.

"Mariah averages thirty-two miles per hour and costs about two cents a mile to operate," says John. Adds his brother Robert: "During our test runs, it averaged about ten miles to a tank of air." The boys have exhibited Mariah at state energy fairs in Oklahoma City and Kansas City.

With an average speed of 32 miles per hour, their car will never win a drag race. But with the high price of gas, it should be a winner at the gas pump!

—Carolyn B. Leonard



GOVERNOR JOHN CARLIN VERY PLEASED WITH SUCCESS OF KANSAS INVENTOR TERRY MILLER. BELIEVES FUTURE OF NATION LIES IN ALTERNATIVE ENERGY FORMS. CARLIN HOPES FOR DEVELOPMENT OF AIR POWERED CARS.

TERRY MILLER HAS A BREEZY REPLY TO THOSE O.P.E.C. BLOWHARDS: AN EFFICIENT AIR-POWERED CAR

PEOPLE Magazine
July 27, 1981

"We have satisfied ourselves we are not whistling in the dark," says Terry Miller, 47, of Crestline, Kans. Nor, he might add, is he full of hot air, though his invention, a pollution-free automobile, is.

Air-powered vehicles are nothing new. One of the earliest patents was issued in 1885 to Charles E. Buell of Springfield, Mass. But Miller, who has put $15 00 and most of the last three years in the project, has built a soon-to-be-patented sequential arrangement in which compressed air is passed from cylinder to cylinder, something like a bucket brigade, to turn an axle. The compressed air's power is thus exhausted through four cylinders, rather than escaping after only one as it did in previous inventions.

Miller's prototype, a three-wheeled, 1,400-pound vehicle, can travel up to 32 mph and has a range of some 17 miles (the consumer version will go 45 miles). He can refuel the compressed-air containers in four minutes, using a windmill, at an overall cost of less than a cent a mile.

Miller, fascinated with engines since childhood, graduated from the Spartan School of Aeronautics in Tulsa. He's licensed as a pilot and an aircraft mechanic instructor. While he was developing his air-powered car, Miller and his second wife, Sharon, made their living by customizing campers.

Currently he is demonstrating the car full-time at state fairs and energy exhibits, although he has not entered it in the $25,000 Los Angeles-to-Rochester, N.Y. rally in September for new alternative-fuel cars. Alcohol cars and salad-oil cars will be among those competing for that prize.

Mass-produced, Miller's car would sell for about $4,000, he estimates, including his modest royalty of about $10 per vehicle. Meanwhile he sells design-and-building instructions for $2. After five Buffalo, Okla. high school students used them to build their own air car, they applied to drive it at Ronald Reagan's inauguration. Their rejection letter arrived the day after the parade.

But the air car is not a toy, Miller insists. "It's a weapon that can be used," he says. "It allows us to think about wind energy as a viable alternative to petroleum products." □

Terry Miller tools down Highway K-26 in Crestline, Kans. In his air-powered prototype. His planned consumer version would carry one passenger plus the driver.

Photograph by Michael Salas

Take one!

★FREE★

UNITED STATES

GOVERNMENT

is quietly furnishing complete building instructions, including engineering drawings, (many pages) on: Where to buy parts: How to assemble: And road test your own

AIR POWERED CAR

You need only write to Commissioner of Patents, Washington DC, 20005. Ask for the building instructions for the only street legal, United States patented, air powered vehicle in the United States. Document number #4,370,857.

G. Beckmann
P. V. Gilli
Thermal
Energy Storage

Basics - Design - Applications
to Power Generation
and Heat Supply

Topics in Energy
Edited by M. Grenon, S. Srinivasan, G. Woite

Springer-Verlag Wien NewYork

P.208-9

8.3.1. Pressurized Air Locomotive

Pressurized air locomotives are used in mines when electric locomotives cannot be used because of danger of explosion. Their advantages are: no waste gas (rather there is a fresh air supply), no heat generation (rather there is a cooling effect by way of cold air exhaust and heat transfer) and simple operation and maintenance.

Fig. 8.3 shows the arrangement. Air taken from bottles with 200 bar storage pressure is throttled to the working pressure of 14 to 20 bar, expanded in the HP cylinder, reheated by ambient air in a tube bundle heat exchanger and further expanded in the LP cylinder. The exhaust air is used in an ejector for sucking ambient air through the reheater [8.4]. Besides this compound engine (with double-acting HP and LP cylinders), small locomotives are equipped with twin engines (double-acting, single-expansion) or with four cylinder engines (single-action, single-expansion). Charging takes place with flexible hoses at charging stations which are supplied with pressurized air from a compressor located above ground.

During discharge (in particular, during fast discharge) all components in contact with the pressurized air will cool down and may even become covered by hoarfrost. This will reduce heat transfer from ambient air and will reduce capacity also. Storage pressure will rise slightly during stops. This rise stems from temperature equalization with ambient.

The pressurized air locomotives which have been built so far have storage pressures of up to 200 bar, storage volumes of up to 25 m^3 in one to three pressure vessels and ranges of up to about 6 km. Fig. 8.4 shows a locomotive of 70 HP (51 kW) and 12.5 kN driving force, with chain drive.

The measured specific output of a locomotive with 120 bar upper and 23 bar lower storage pressure was about 10 000 kJ/m^3 [8.5]. The theoretical output in this pressure range is about 42 000 kJ/m^3. Therefore, the discharge efficiency is about 24%. Losses consist of three main parts, the parts being of about equal size: Throttling losses at the pressure-reducing valve, losses which stem from non-isothermal expansion; and throttling losses, mechanical losses and exhaust losses of the engine. Thus, the efficiency of the pressurized air locomotive is lower than that of either the electric locomotive, or the electric storage (accumulator) locomotive, or the diesel locomotive.

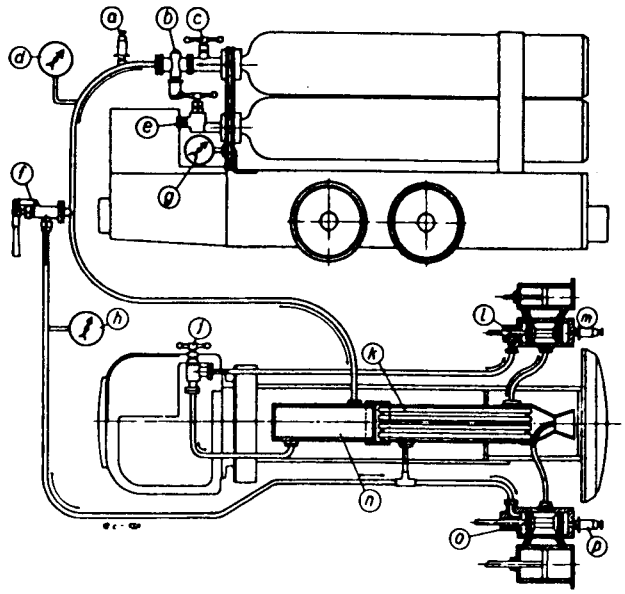


Fig. 8.3. Flow sheet of a pressurized air locomotive [8.4]
a safety valve behind pressure control valve, *b* pressure control valve (discharge valve), *c* shut-off valve, *d* pressure indicator (range 0–36 bar), *e* charge valve, *f* fresh air valve, *g* storage pressure indicator, *h* pressure indicator (range 0–16 bar), *j* governor valve, *k* reheater, *l* HP cylinder, *m* safety valve before HP cylinder, *n* intermediate vessel, *o* LP cylinder, *p* safety valve before LP cylinder

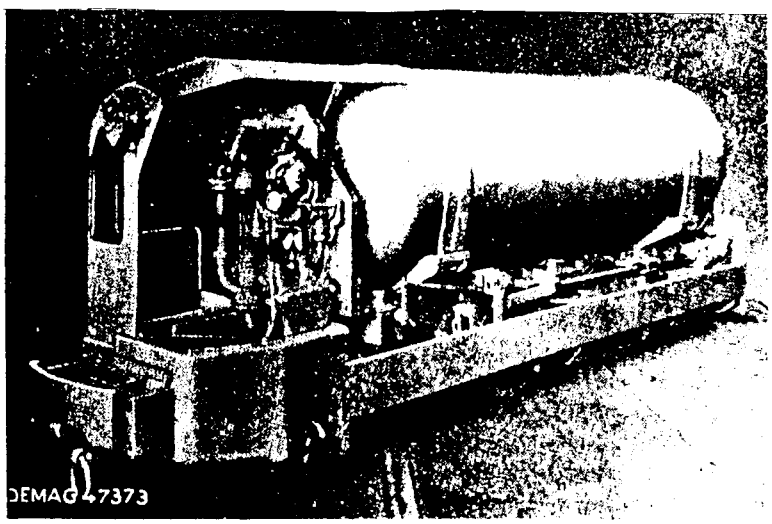


Fig. 8.4. 70 HP pressurized air locomotive [8.4]

United States Patent [19]

Coester

[11] **Patent Number: 4,587,906**

[45] **Date of Patent: May 13, 1986**

[54] **PNEUMATIC PROPULSION SYSTEM FOR CAR AND PASSENGER VEHICLES**

[76] Inventor: **Oskar H. W. Coester**, Rua David Francisco Mauricio 85, Porto Alegre, Rio Grande do Sul, Brazil

[21] Appl. No.: **190,926**

[22] Filed: **Sep. 26, 1980**

Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 909,434, May 25, 1978, abandoned.

[30] **Foreign Application Priority Data**

Sep. 28, 1979 [BR] Brazil 7906255

[51] **Int. Cl.**[4] **B60U 3/04;** B61B 13/08

[52] **U.S. Cl.** **104/156;** 104/161

[58] **Field of Search** ..... 104/156, 155, 157, 158, 104/159, 160, 161, 140, 139, 154, 23 FS, 138 R, 298, 299, 301, 305; 92/88; 244/63; 246/6

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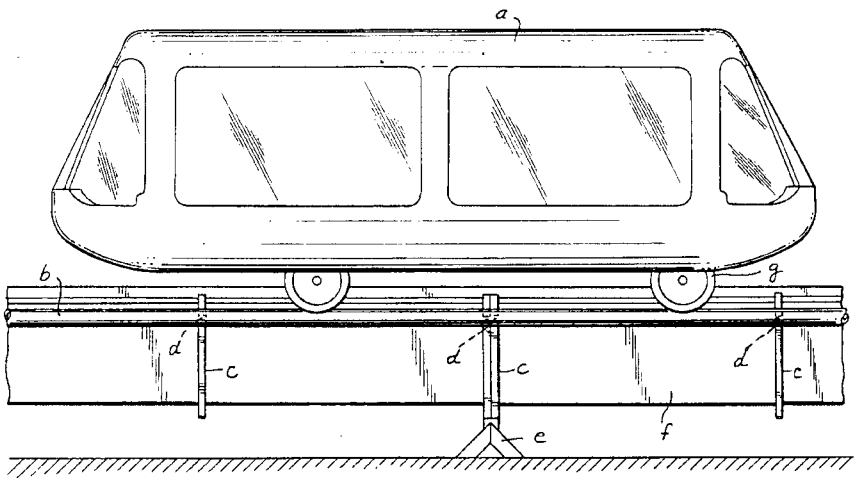
Primary Examiner—John J. Love
Assistant Examiner—Mitchell J. Hill
Attorney, Agent, or Firm—Greene, Callmann & Durr

[57] **ABSTRACT**

A system for propelling vehicles for carrying passengers or cargo comprises a longitudinal duct, having a slit at the top and a pair of rails or tracks. A vehicle is provided to run on the tracks and has a fin which projects into the duct to substantially fill the same. Differential air pressure is applied to the duct to cause the fin to move along the duct and carry the vehicle with it. The duct may include several stations with means to produce differential air pressure between the separate stations. A braking device operates to apply brakes when the pressure on both sides of the fin is substantially the same. Preferably the vehicle contains no internal control for the fin or air pressure so that it can be controlled from the outside by the device for forwarding the differential air pressure.

4 Claims, 15 Drawing Figures



First page of a 15 page patent.

United States Patent [19]

Coester

[11] Patent Number: 4,658,732

[45] Date of Patent: Apr. 21, 1987

[54] PNEUMATIC PROPULSION SYSTEM FOR FREIGHT AND/OR PASSENGER VEHICLES

[76] Inventor: Oskar H. W. Coester, Rua David Francisco Mauricio 85, Porto Alegre, Rio Grande do Sul, Brazil

[21] Appl. No.: 596,434

[22] Filed: Apr. 3, 1984

[30] Foreign Application Priority Data

Apr. 4, 1983 [BR] Brazil ..... PI 8301706

[51] Int. Cl.[4] B61B 13/12

[52] U.S. Cl. 104/156; 104/161

[58] Field of Search ..... 104/155, 156, 161, 23 FS, 104/245, 288; 105/343, 348; 137/527.8

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Primary Examiner—Robert B. Reeves

Assistant Examiner—Scott H. Werny

Attorney, Agent, or Firm—Ostrolenk, Faber, Gerb & Soffen

[57] ABSTRACT

A pneumatic propulsion system for passenger vehicles is constituted by a structural beam, composed of modular elements end-supported on pillars. The beam supports the trackway and provides an air duct for pneumatic propulsion of vehicles. A longitudinal slit in the top surface of the beam is sealed by flexible flaps and that press against each other to seal off the duct, while allowing for the passage of support mast. Airflow for propulsion of the vehicle is generated by a stationary airflow generator, which feeds the air propulsion duct by way of connecting ducts and which is outfitted with a set of four butterfly control valves that are controlled by a command and control system of flow and pressure condition in the duct which actuates the valves pneumatically, allowing automatic or manual selection of "suction" or "pressure" conditions in the duct. Shutoff valves are fitted to openings in the bottom surface of the beam to allow isolation of segments of the propulsion air duct or, alternatively, its venting to connecting ducts or to the atmosphere, allowing by means of a combination of several valves to delimit a specific propulsion air circuit. Traction of the vehicles results from the difference in pressure that is established on opposite sides of propulsion plate by the effect of the airflow generated by the generator unit. A support mast connects to a propulsion plate jointly with a traction arm which transfers the resultant tractive force to the vehicle. Adjustable decompression panels assembled on the propulsion plate assure that a maximum safe pressure differential limit is not exceeded, said limit being controlled by the action of a set of springs positioned on both sides of the propulsion plate.

19 Claims, 22 Drawing Figures

A 30-page patent. See also Aeromovel.com

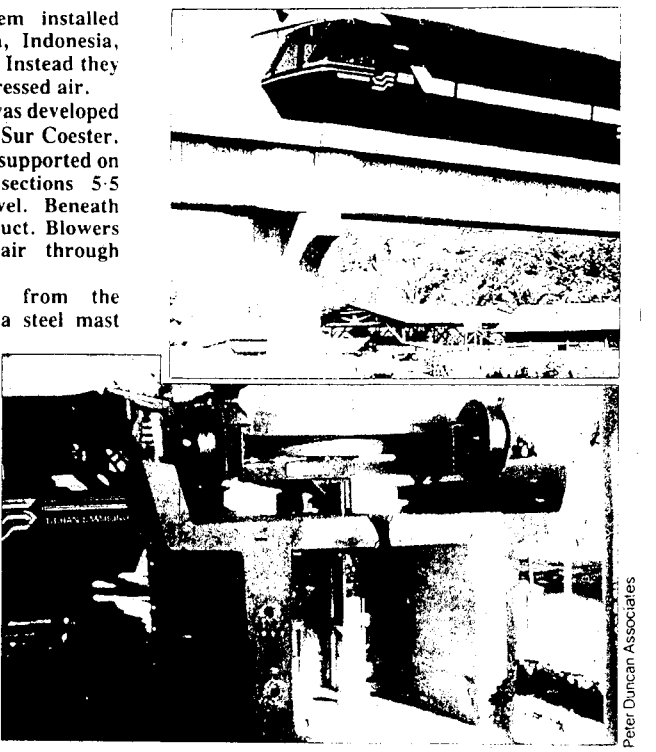
Air-driven train gives commuters a smoother ride

A NEW railway system installed this year in Jakarta, Indonesia, has trains with no engines. Instead they are pushed along by compressed air.

The Aeromovel system was developed by the Brazilian company Sur Coester. It has elevated steel tracks supported on concrete legs and box sections 5·5 metres above ground level. Beneath each track is a concrete duct. Blowers along the route force air through the duct.

Projecting downwards from the bottom of the vehicle is a steel mast which passes through a slot in the top of the duct and holds a steel sail in the air flow, completely blocking the duct. If the force and direction of flow of the air is varied the vehicles will respond accordingly.

Without the weight of the engines, the vehicles are very light. This cuts noise and vibration, giving a smooth ride. The train can also take very tight radius turns. □



Peter Duncan Associates

New Scientist, 11-24-90, p. 30

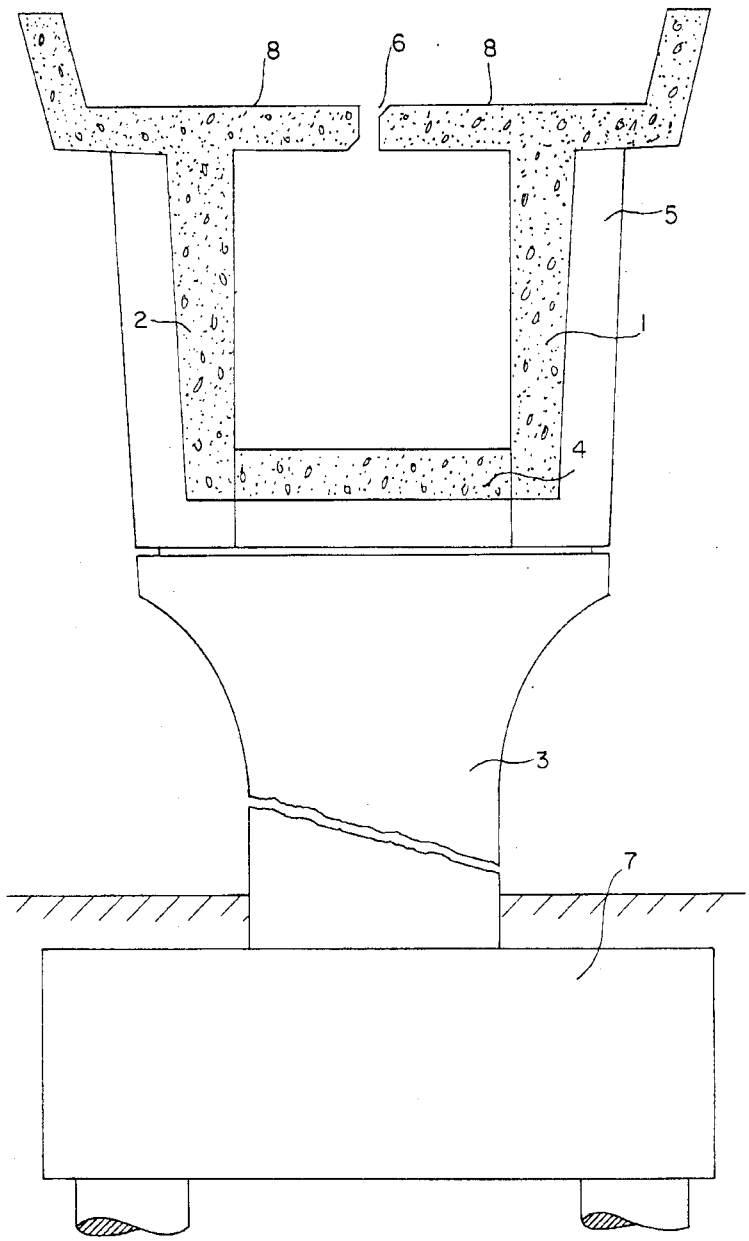


FIG. 1

A Transportation System Called Aeromovel, Like Other Urban Mass Transit Concepts, Waits in the Wings for Its Time on Center Stage.

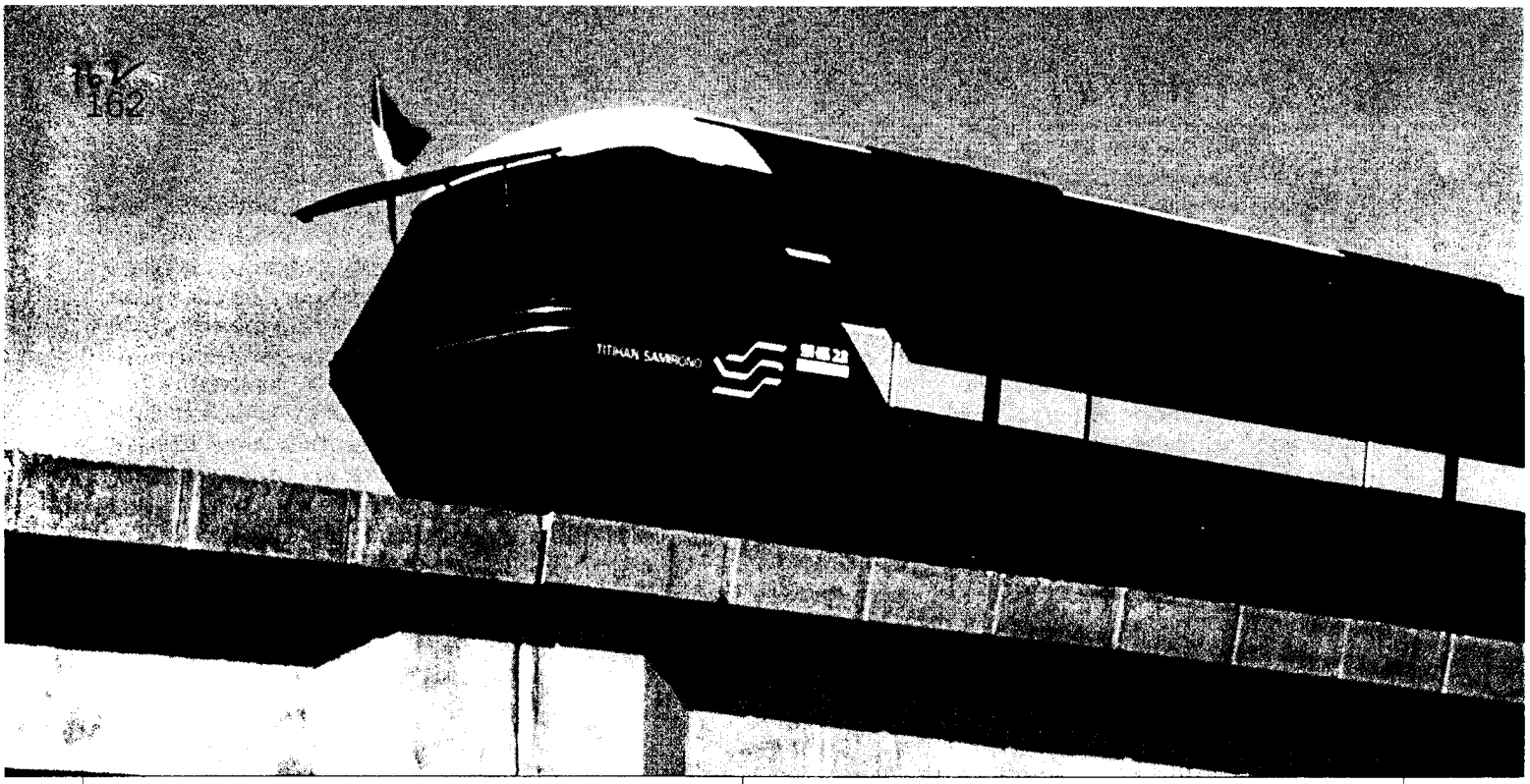
Air Travel for Mass Transit

By the 1870s, traffic in some American cities was approaching gridlock. Horse-drawn streetcars that had helped cities grow stood nose to bumper on downtown streets, competing with carriages, carts, and pedestrians for forward movement. In 1866 in New York City, an overpass was built for people to cross lower Broadway. In winter there was snow to contend with, at least in northern climes, and everywhere and in all seasons there was manure. Mass transit had evolved some since the horse-powered omnibus of the late 1820s, but new technologies did not always find ready acceptance, and financial downturns could restrict capital investment.

The notion of elevated cars coursing above the crowd gained appeal. In *A Century of Service—the Story of Public Transportation in North America*, Brian Cudahy notes, "There were many exotic ideas suggested for elevated transit—overhead viaducts for horse cars, enclosed tubes suspended over streets through which cars could be shot by air pressure, even elevated moving sidewalks."

Transit builders in New York, perhaps the most congested of America's cities, ultimately settled on adapting steam technology. They used small locomotives to pull cars over tracks two or more stories high. Although an improvement, this did not represent mobility perfected; the Els spread soot, startled horses, and sometimes started fires.

Today, a century later, the concept of using air pressure to move elevated transit vehicles has made another appearance. A Brazilian company, which licensed an air-powered people mover in Jakarta, Indonesia, in 1989, is pursuing further possibilities in Sweden, Thailand, Pakistan, and the United States. Lee Rogers, a transport economist and consultant, notes that there is a lot of interest in people movers in the United States, pointing to



cities in Georgia, Florida, and Maryland as examples. "But no one," he says, "is willing to be the pioneer. Once it goes in, I think there will be more appreciation of it." In the 1940s, Rogers notes, people were more interested in better radios than in television. In those days, businessmen didn't fly. He asks, "Would you have invested in Pullman or DC-3s?"

The Brazilian company is Sur Coester S.A., and its system is called Aeromovel. The company claims it is less expensive, safer, and more environmentally friendly than buses, conventional or light rail, and other automated guideway systems, whether these modes are powered by electricity, magnetic levitation, or internal combustion.

In this era of air pollution, oil concerns, traffic congestion, Edge Cities, altered commuting patterns, and sporadically used rail systems, many metro areas are seeking alternatives. One such option is automated guided transit (AGT). It is a potential multibillion-dollar market and embraces not only regular commuter transportation but also specialized situations at sports complexes, shopping malls, resorts, amusement parks, and universities. George Swede, a Los Angeles transportation development specialist, reports there are more than 44 AGT systems currently operating worldwide. There are a couple of dozen more in design or under construction. There is no question as to whether or not there are enough sites to use all these AGTs. One Department of Transportation study said more than 1500 potential sites exist in the United States.

COST-COMPETITIVE

Although the cost of instituting a new system is typically high, the price tag for the Aeromovel is competitive. For example, capital costs, says Rogers, run one-third of light rail. Operational cost is about $2.80 per vehicle mile. This can be compared with $11 for Miami's people-mover system and $14 for Detroit's.

These costs result from lower vehicle weights and construction materials, lower energy expense, and reduced labor. There are no drivers, and maintenance is less demanding. Although the automation equipment required for the system is not inexpensive, 70 percent of the total cost for Aeromovel is in civil works, that is beams and foundations. And that's also low. Lighter-weight cars mean lighter and fewer support beams.

Because of these lower costs, Aeromovel can attract private investment. It did so in Jakarta...to the tune of $10,000,000 for a 3.2 km loop with six stations. In times of tight government budgets, private-sector participation becomes especially important to mass transit. Curiously, this concept is not new. All mass-transit ventures were originally privately owned and operated. Boston's subway, the first underground in the nation, was also the first system to use public funding. That was close to the turn of the century, in 1897. By the mid-1940s, almost all mass transit lines in the United States were publicly owned and operated. Today, smaller-scale people-mover systems serving business districts, commercial centers, and tourist attractions have brought back private funding.

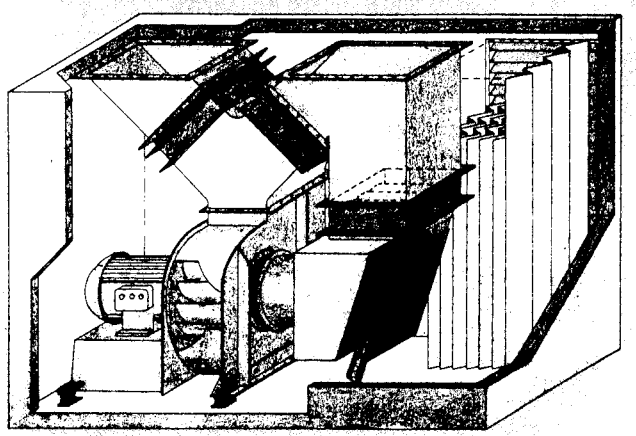
According to George Swede, there are nonmonetary factors that can influence the selection of people-mover systems. For example, there is the importance of a progressive image that a sleek and efficient transit service can impart to a city. That, in turn, can help the community compete for conventions. And that boosts downtown real estate values. Such factors are, again, echoes from the early days of mass transit.

Aeromovel was developed by Oskar Coester, an inventor-businessman with a background in avionics and nautical engineering. In 1982–83, he built a demonstration line at Porto Alegre in southern Brazil. It was a 1 km line that Coester planned to extend to serve the commercial district. A change in government cooled investment, as it is wont to do, and the scheme has remained in limbo ever since. However, it continues to serve as a demo and has given its designers a decade of practical maintenance experience. From this have come many refinements to the original design.

Aeromovel's antecedents predate the visionary Big Apple proposals floated in the latter half of the nineteenth century. Indeed, they date from England, circa 1847, when Isambard Brunel built his "atmospheric railway" along a 52-mile stretch of the Dover coast. It used a between-the-rails vacuum tube and stationary pumping engines. The cars moved at speeds exceeding 60 mph. However, Brunel's plans were soon deflated when the line proved commercially and technologically infeasible. The leather tube flaps, for example, quickly deteriorated with use.

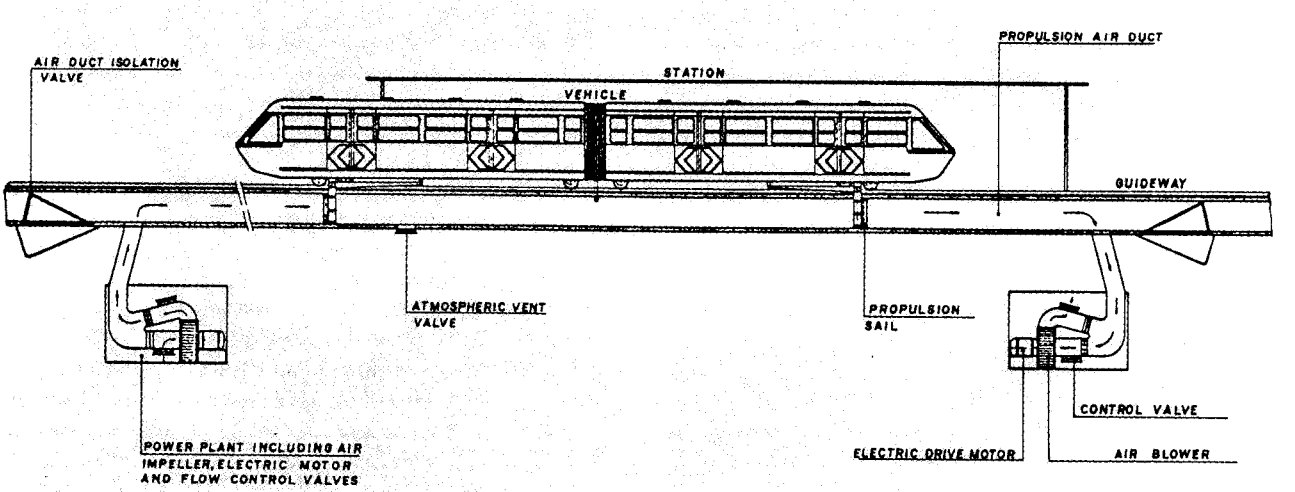
Today's designs use plastics, rubber, steel, and concrete, and, especially important, computerized automation. Yet, Aeromovel remains relatively simple. The vehicles are passive—that is, they lack motors—and operate with steel-flanged wheels on steel rails. The wheels are more akin to bearings in that they're not used for traction. There is a concrete guideway with a slot running its length. The vehicle has a rigid steel "sail" or plate that fits precisely in a hollow duct in this guideway. The sail measures 1521 square inches and is attached to the underside of the chassis by a pylon. Conventional blowers, of the type used in tunnels, supply air at 50,000 cfm through adjustable valves in the duct. The air, at a pressure of 2 psi, pushes against the sail. The Aeromovel car moves at speeds of 50 mph. It reportedly can handle 90-degree curves at 6 mph, and 10 percent upgrades.

Blowers are located in closed containers along the system and are of different sizes to best serve distinct segments of the route. More powerful blowers are designated for grades; others are sized for curves, lower grades, and straightaways. This keeps energy consumption down. Energy conservation is also enhanced because of the lightweight



Drawings prepared by The Match Institution for a brochure published by Sur Coester S/A show propulsion elements of a typical system. The cutaway is of a typical containerized power plant assembly for an Aeromovel installation.

As can be seen in the pictures to the right, wheels are like bearings; they are not used for traction, as are conventional wheels. Propulsion is provided by air pressure against a "sail" that fits snugly in a hollow duct in the guideway (bottom left). Top picture, far right, shows an Aeromovel unit being placed on the wheel carriage on the track.



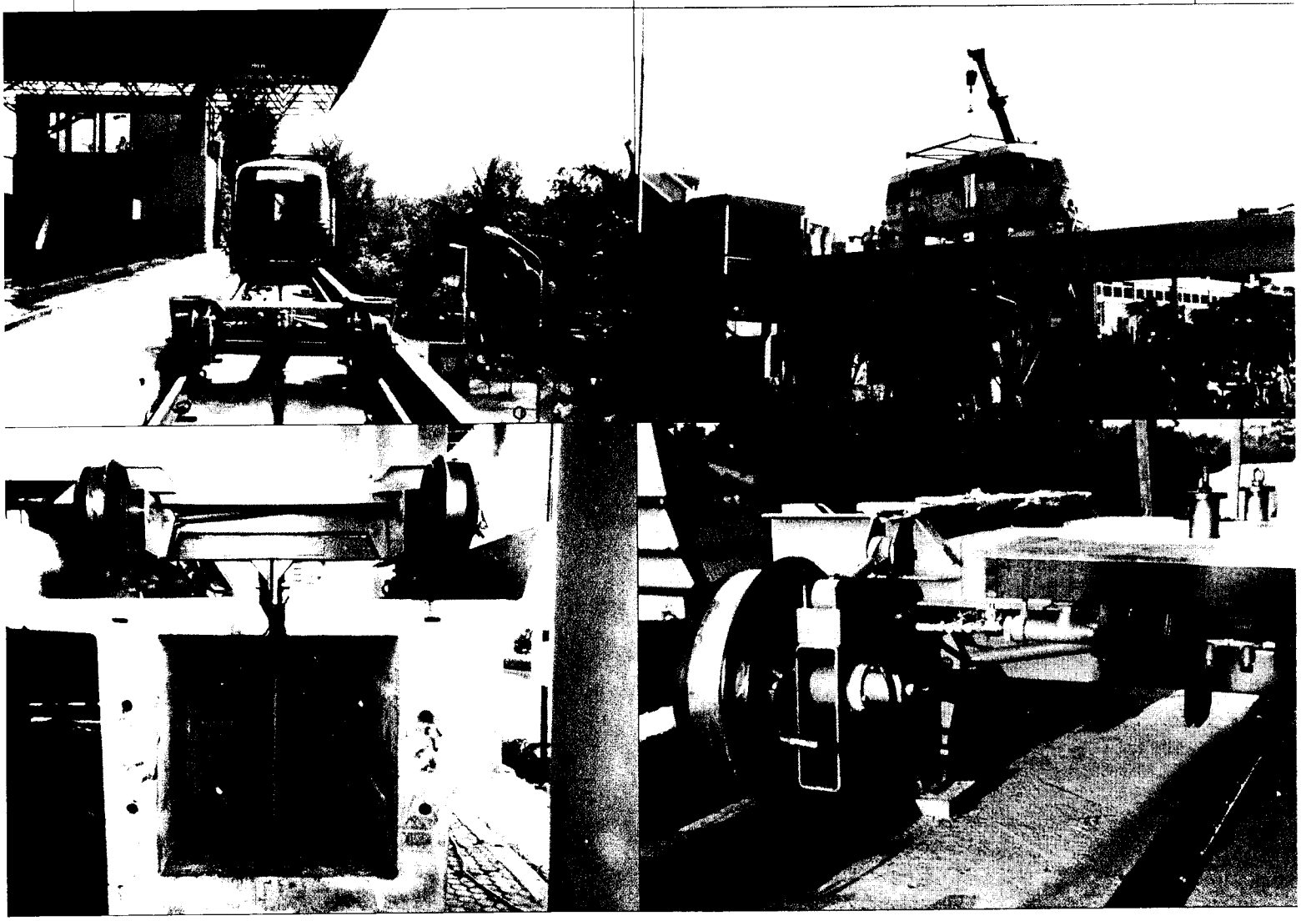
and off-track propulsion system, and the fact that there are no gears, power train, or intervening electrical circuits. Based on experience in industry, the blowers should run for 100,000 hours without a major failure.

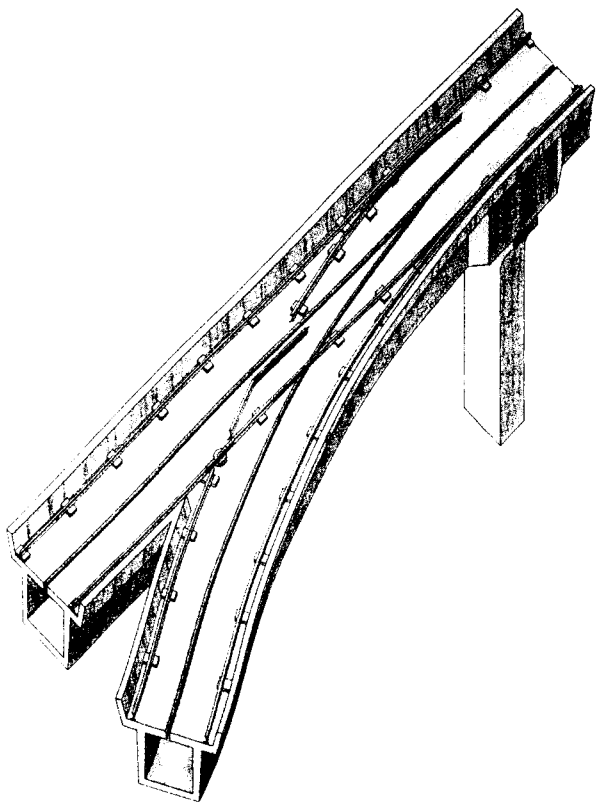
The ultralight articulated cars weigh 9 tons empty. That is one-third the weight of a light-rail vehicle. Because they carry no engines, there is added passenger capacity for a given energy input. In fact, passenger payload approaches 70 percent for Aeromovel; for a New York City subway, it's 33 percent.

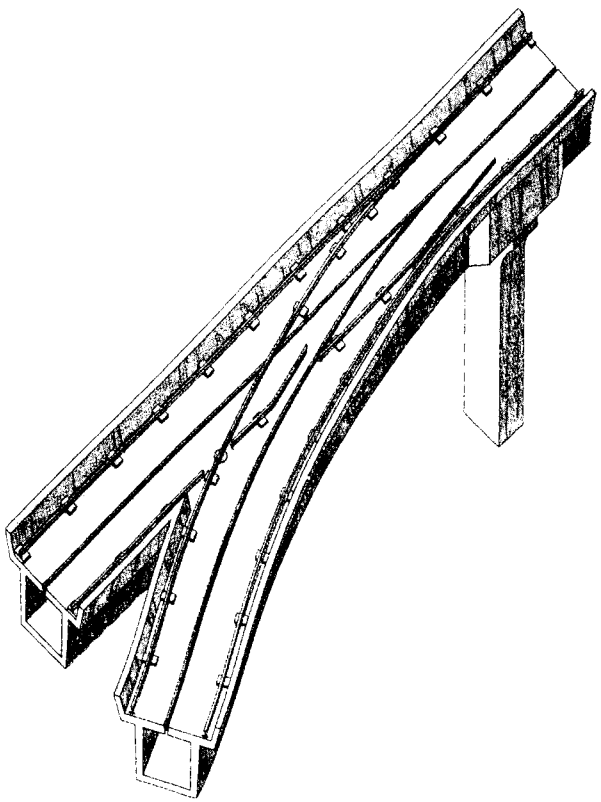
Although most AGT systems use a third rail with rotary electric motors on the cars themselves, there are some passive designs of note. These include people movers at Disneyland and Disneyworld that use, respectively, linear induction motors and powered wheels in the guideway. A system at Duke University uses pneumatic levitation. At the Circus-Circus Hotel in Las Vegas, it's cable. Perhaps the most famous system is San Francisco's cable cars. They are the sole survivors of an era that once extensively used this urban transit mode.

Aeromovel may not be a magic carpet ride, but it is smooth and quiet. According to Lee Rogers, the lack of engines aboard the cars translates into fewer vibrations and less noise. One test revealed a sound level of 63 dB between stations. This suggests to Rogers that an Aeromovel system could actually enter buildings, even older ones not designed for such traffic. Another plus on the environmental side is that the vehicles and driving machinery emit no pollutants.

Safety is another area where Aeromovel seems to have a competitive edge. Buffers of compressed air between cars prevent rear-end collisions, and valves in the duct separate one route segment from another. Hydraulic disk brakes augment reverse air thrust in stopping; both are controlled by microprocessors. At a station stop, the blower idles and air pressure drops to zero. In case of power failure, the air valves automatically close, bringing cars to a halt. The slotted mast/sail device precludes derailment, and Aeromovel has no electrified third rail. AGTs as a class, observes George Swede in his 1992 report entitled "Automated Guideway Transit Systems," have performed exceptionally well from a safety standpoint. There have been no reported passenger fatalities due to failure of the automated control systems.







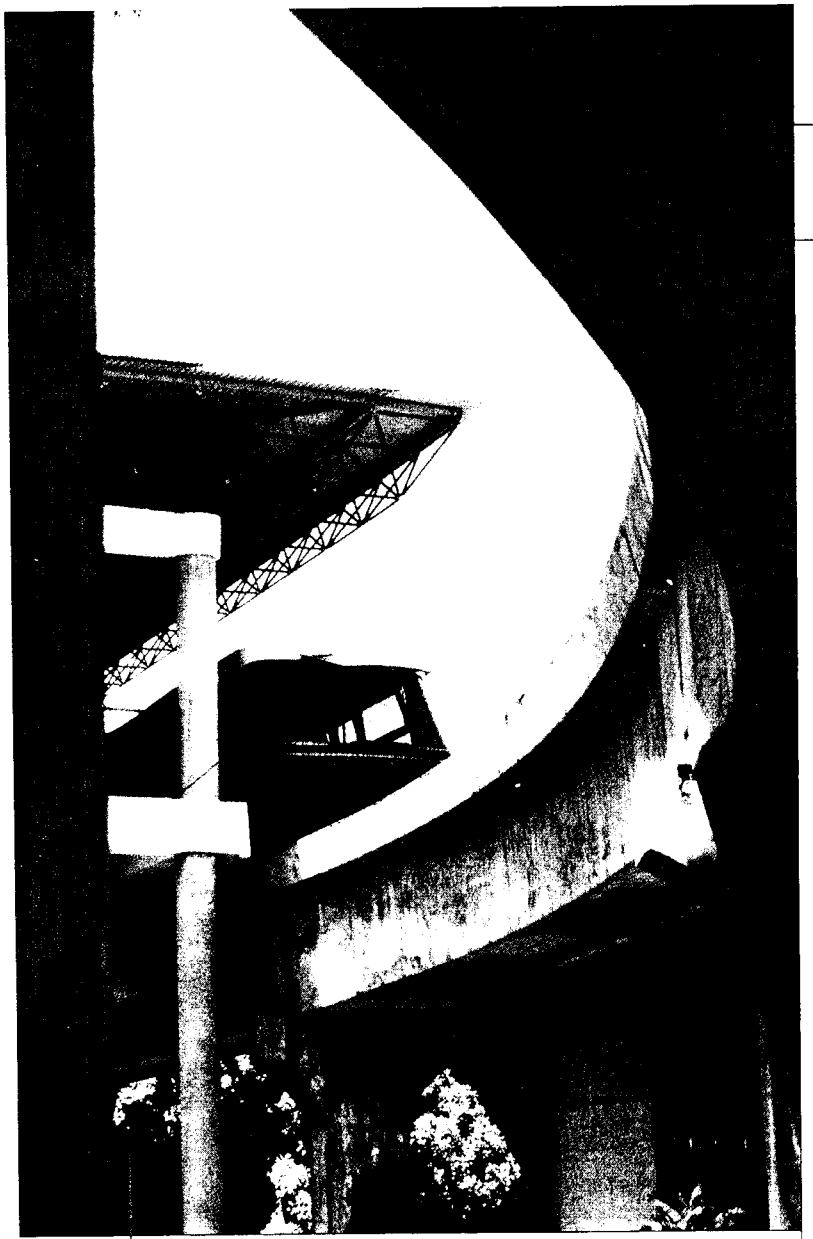
Aeromovel switching is similar to standard railroad switching with one more crossover element being moved to free the center slit in use. Drawings show a switch in its two positions; the photograph shows a typical switching area in an Aeromovel guideway installation.

With Aeromovel, valve-regulated air flow is based on data received from magnetic sensors in the trackbed. These are monitored by a central command post. Alternatively, operators at each station can manually control air flow with conventional industrial-type valves. A visual display on the operator's control panel shows the position of all valves. Digital indicators exhibit the speed of vehicles in each route segment, based on information from the sensors. Vehicle location on the route is also shown in a luminous display at each section control booth and at the central command post.

Some critics call Aeromovel too light, too flimsy. These are people who, according to Rogers, have railroad backgrounds. Admittedly, Aeromovel cars require no heavy undercarriage and they have no couplings. But, says Rogers, the system has a good life span. The prefab, cable-stressed concrete beams have a designed service life of 35 years. When necessary, customizing is possible. For example, the piers in Jakarta were built to withstand an earthquake measuring 6.5 on the Richter scale. This was a redundant precaution. Borrowing from Japanese transit technology, the Aeromovel system shuts down when vibrations reach 4 on the Richter scale.

And what about comfort? In public transit's early days, that really wasn't part of the deal. Novelty, convenience, and sometimes relative speed and efficiency, were; but not comfort. One New York City newspaper in the mid-1860s said riding the local mass transit was "modern martyrdom succinctly defined." With the Aeromovel, some might argue the more things change the more they stay the same. The essential Aeromovel system is mainly designed for standees making short trips, although

Aeromovel



Here is graphic evidence that Aeromovel people movers can handle tight curves.

additional seats can be put into the interior space.

But being a standee is not the strain it is on, say, a subway. Air propulsion means jerk-free acceleration and deceleration, and pneumatic air-bag suspension supplies a bump-free ride. Heating and air conditioning, although not part of the Porto Alegre and Jakarta operations, would almost certainly be added to any version deployed in this country. The main option here is an auxiliary power unit running on fuel carried in a small cylinder. This would be ethanol, LPG, or propane, and would run the auxiliary power unit for 18 hours without refill. Batteries would not be logical; they would add weight and, says Rogers, they have problems in endurance. There's no intent of adding a third rail simply to provide electricity for air conditioning.

GAINING RIDERSHIP

No matter what the mode, to gain and sustain ridership, mass transit must be efficient and reliable. It must be "there." People are far more prone to use such transit if they know they won't have to wait for more than a few minutes. AGT people movers perform well in this sector. Aeromovel, for example, can run 1- to 2-minute schedules between cars and move 2000 to 12,000 riders per hour, perhaps making 30 stops per hour at peak times. Minimal headways, which Rogers predicts could drop to a single minute in a few years, result from automated, precision timing; the distances involved; and rapid loading and unloading. There are four sets of double doors per side.

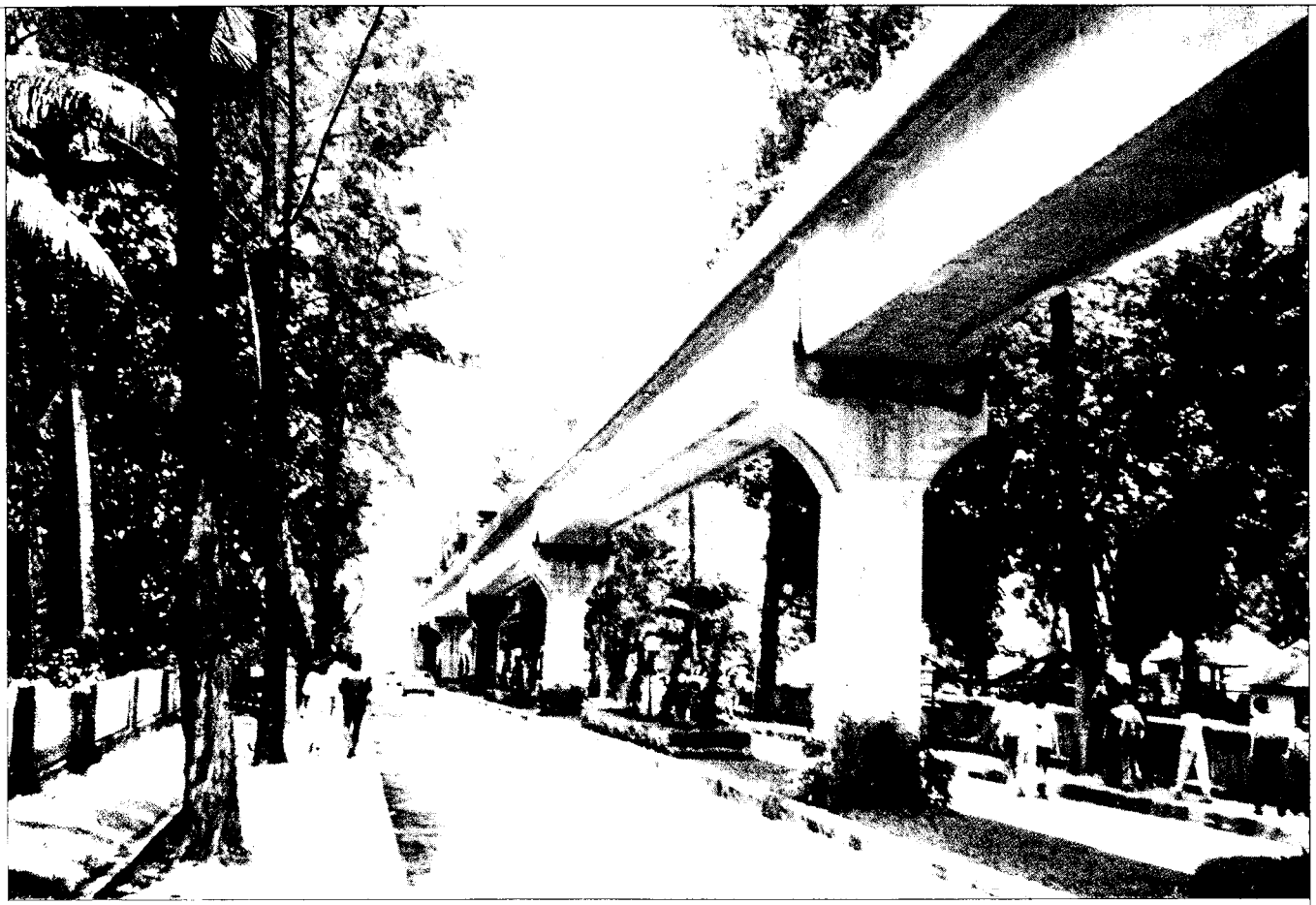
Because Aeromovel's standard car is 80 feet long and can stop on a dime, or at least within 20 inches of its target, station platforms can also be about 80 feet long. Thus they can easily be set into an existing environment. On the other hand, unless a conventional transport system is built with a city or project, it must be retrofitted. The small stations required by an AGT system can be spaced a half mile or less apart. This means better destination access. It goes without saying that this, in turn, encourages ridership.

Aeromovel can be constructed at-grade or even underground. The latter is more expensive; the former, potentially obstructive. An El seems best. It offers an exclusive, fully secure right-of-way. The elevated guideway design of the Aeromovel permits narrow contours for the routes. They can follow roadway medians, old rail lines, and minor waterways. Support columns are spaced about every 80 feet and stand as high as local traffic needs dictate. Typically this is 14 to 15 feet. Modular beams permit quick and easy construction—Jakarta's system was completed in 8 months.

Aeromovel technology, and AGTs in general, has potential for industrial and commercial applications. It can move materials and bulk goods as well as people, but that hasn't happened yet. Specialization so far has involved theme parks and airports. But the possibilities again hearken back to niches carved out by trolleys of years gone by. In some cities early in this century, they carried funeral corteges, sprinkled water on dusty streets, picked up garbage, and delivered milk.

Conceivably, the immediate future of urban mass transit lies, at least in part, with specialization, short hauls, and frequent runs. Work habits and styles are changing. Flexibility is ascendant, and timeliness and efficiency spill over to the leisure side. Public transportation, to be truly viable, should be useful for everyone all the time, not just for commuters along established corridors at traditional times of the day.

Lee Rogers says he doesn't foresee any great technical advances or breakthroughs in the next 10 to 20 years. He observes that computers and fax machines do some of the "commuting" for business



Aeromovel was developed by Oskar Coester. Installation in Brazil has served as a demo and has given designers practical maintenance experience. Jakarta setup took 8 months. With the coming Olympics, an Aeromovel system might solve Atlanta's people-moving concerns.

today. He also feels that although mass transit planners and designers won't admit it, automobiles have developed comparatively more efficiency and improvement over the past decade or so.

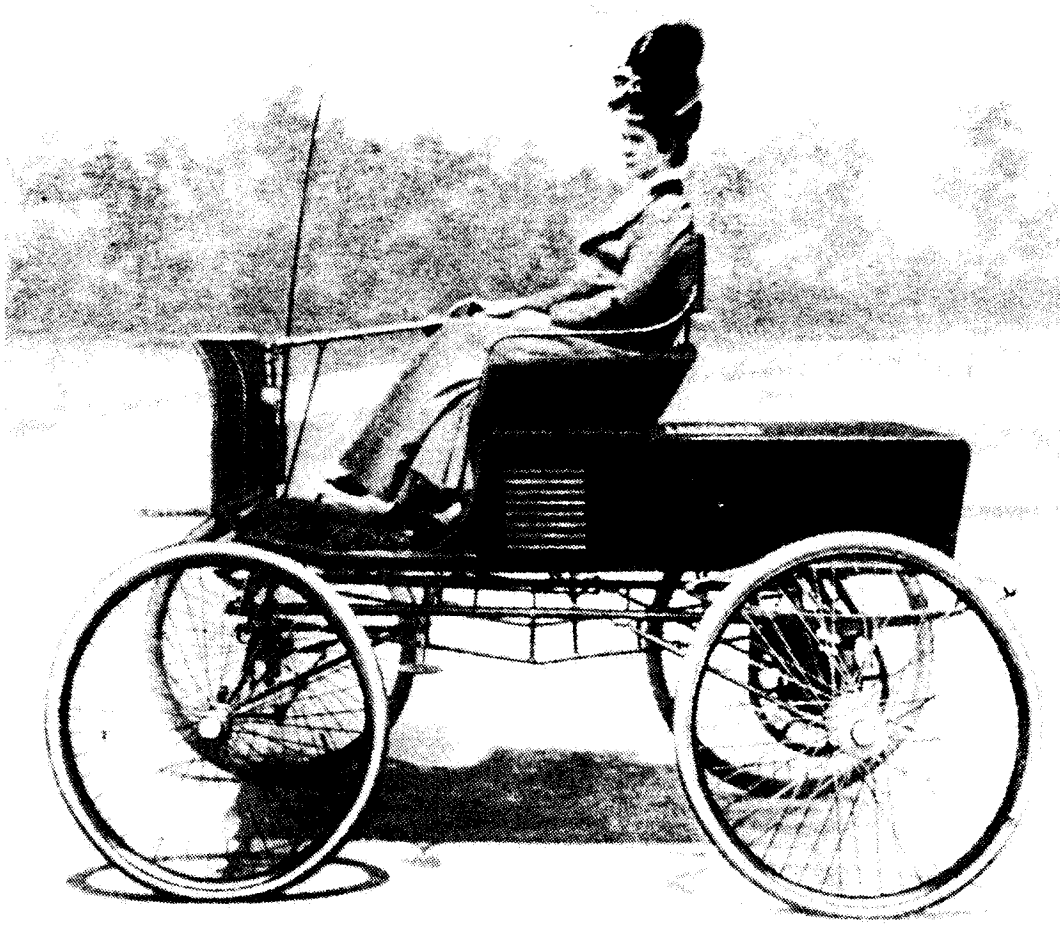
OLYMPICS AND ATLANTA

In Atlanta, Ga., officials face not only the challenges of urban growth and mobility but also the influx of visitors for the 1996 Olympics. Last spring they began evaluating possibilities for people movers for downtown, midtown, and the Buckhead bistro district. According to Sam Massell, head of the Buckhead Coalition, a business group seeking a people-mover system for a 6-mile stretch through the commercial district, a feasibility study will consider mode, cost, route, and other factors. The study should be completed by spring 1993. A special property tax on local businesses would provide funding for the system that would connect with the existing light-rail metro transit operation (MARTA).

The Aeromovel system is a potential candidate because of costs, capacity, and implementation time. The city would like the same mode/technology for all three regions and hopes that the people movers would increase MARTA patronage by acting as feeders or collectors. Massell predicts wide acceptance of the Buckhead transit development that would charge passengers nothing while whisking them through lobbies of buildings and depositing them at hotels and restaurants. "It's definitely a way to cement into the future the economic viability of the Buckhead business core," he says.

In Atlanta, the plan seems to be that people movers would not cut through neighborhoods, but rather become part of a particular neighborhood, serving residential and commercial needs. According to the city's director of Planning & Development, Leon Eplan, the idea is not simply to move people and goods, but to build communities.

In 1882, one transit industry executive listed three major problems facing the industry—the best way of feeding and caring for horses, the best pattern and manufacture of cars, and the honesty of conductors. The first and third no longer pertain. The second remains. By extension it may include affordable technology and a transit mechanism the public not only accepts, but partakes of, finds beneficial, and integrates into its life-style.



It has been said that there is nothing new under the sun. Files of potential articles in the editorial office today contain one marked "Pneumatic Car." It will discuss current activities in the area. The January 1900 issue showed this automobile operated by compressed air and built by The American Vehicle Company, NY.

ABOVE: Compressed Air Magazine, March 1996, page 15